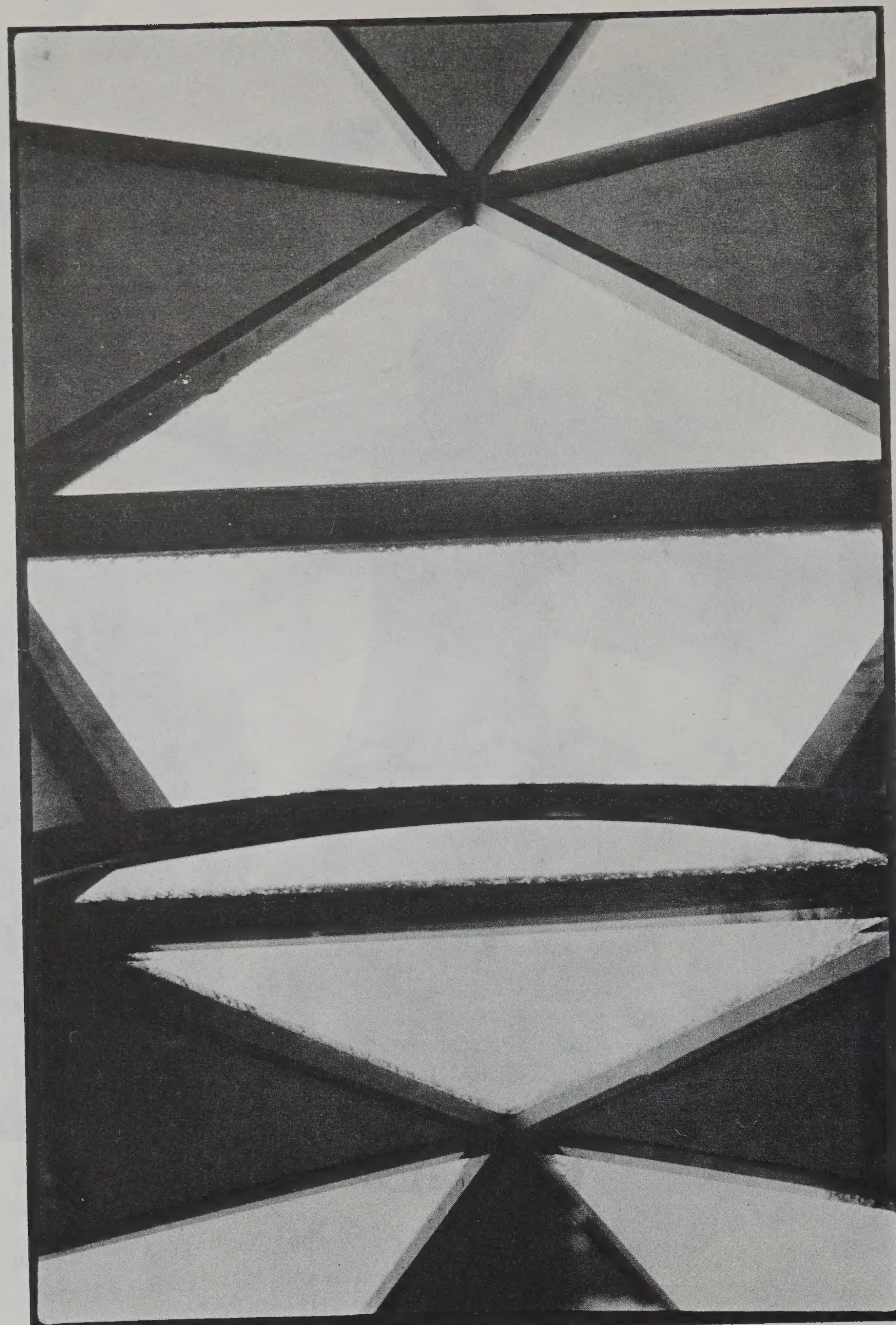
DOMEBOOK ONE

$3

Contents



Ten domes were built in four months at an experimental high school in the California hills. Three of the domes were built almost entirely by 15-17 year olds.

The book was written and assembled shortly thereafter—in haste—as we are eager to communicate our experiences and discoveries.

The cycle so far has been something like this: need/design/build/inhabit/communicate/need . . .

We hope to continue this process and will publish another book as soon as enough new information assembles.

Send us your thoughts, discoveries, criticisms. If you build a dome, tell us what it's like living in the new space.

We were inspired largely by R. Buckminster Fuller.

Stewart Brand's trailblazing with the *Whole Earth Catalog* encouraged us to attempt our own publication.

DOMEBOOK ONE is the first publication of Pacific Domes, a non-profit educational corporation.

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DOMEBOOK ONE was put together in 14 days at the Whole Earth Catalog production garage by:

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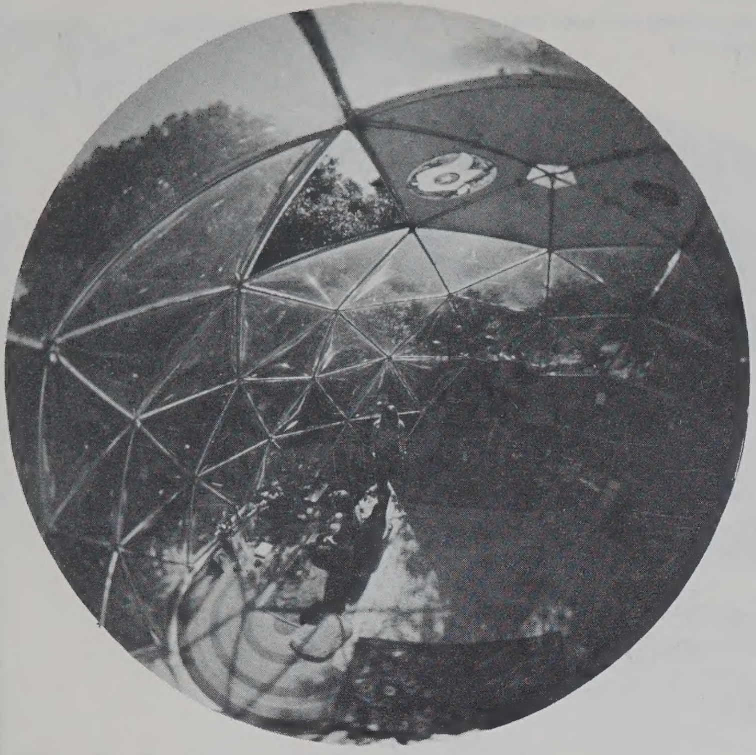


DOMEBOOK ONE is our attempt at communicating the state of the art of domebuilding, spring 1970.

These are domes that we designed, built, and live in; we are thereby testing the "physical projection" of our fantasies.

These are domes built by individuals in the 70's that could well be prototypes for future industrial production of low-cost housing.

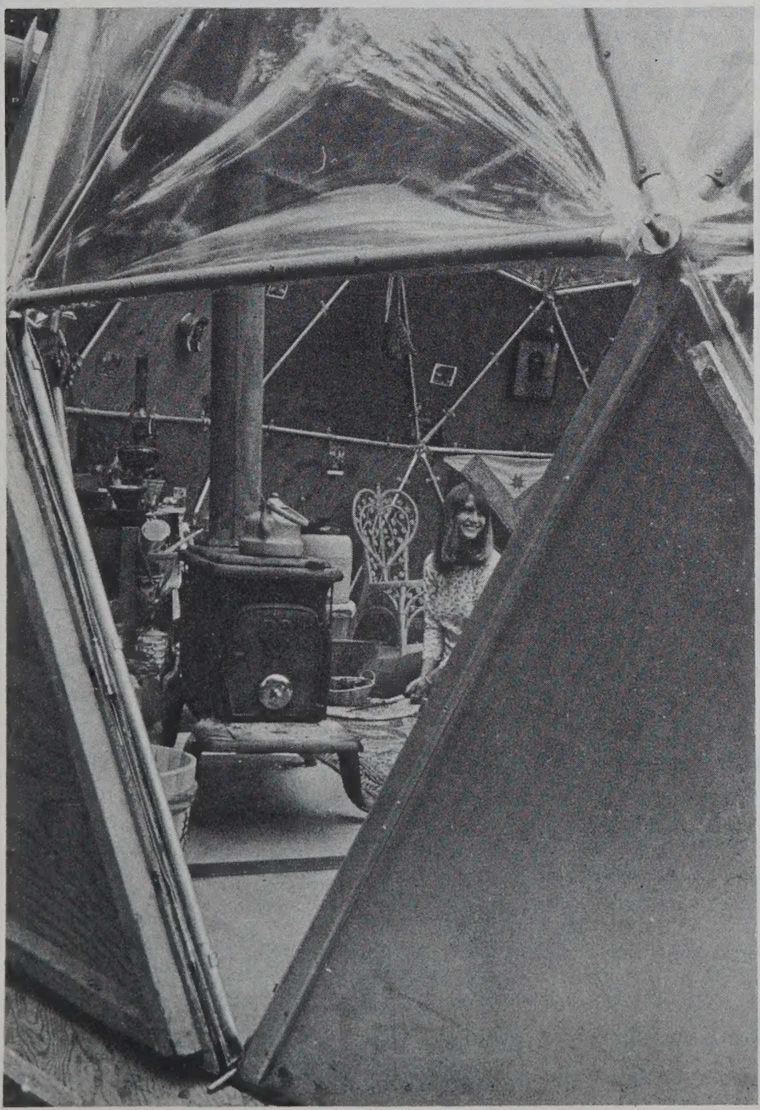
New life contained within new geometrical shapes and patterns. Shelters designed and built with beauty, efficiency and grace. A skin instead of a roof overhead, a light membrane protecting you from the rain. Symbols of quick escape from the cities. Economical and orderly use of materials. Minimum violation of land. A structural system so simple that anyone willing to exercise a reasonable amount of care and "quality control" can build his own shelter.

These factors now cause domes to emerge:

1—New materials, partially a fall-out from the space program, are now available to everyone. Silicone caulks, polyurethane foam, clear ultra-violet resistant flexible vinyl, etc. These are needed to make domes work.

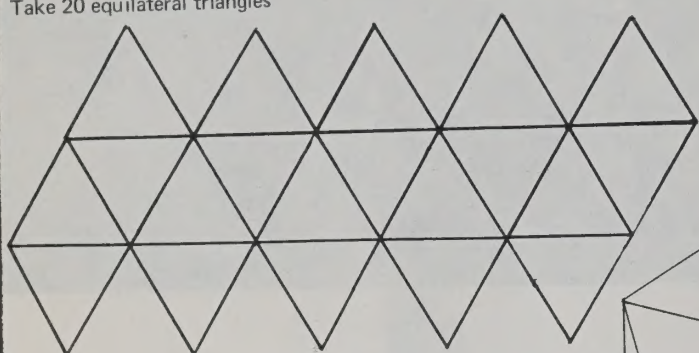
2—A simple and efficient geometry for spheres—geodesics—is now readily accessible (herein).

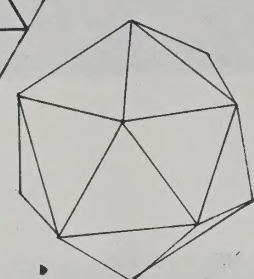
3—An overwhelming desire for new forms, circumvention of the utter inefficiency and wastefulness of the "craft and graft" building industry, and a newly-emerging lifestyle.



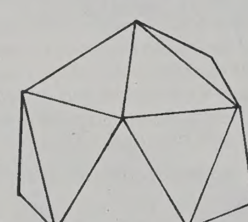
simple geodesics

Take 20 equilateral triangles





Join them together, five triangles around each vertex to make an Icosahedron which is structurally stable, even with **rubber connectors** at **vertices.**

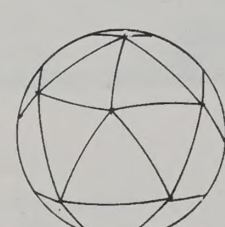


We could make a structure from the icosahedron by removing the bottom five triangles and placing it on the ground. It sits flat.

Dome

Removing the five triangles makes the structure unstable, but once it is firmly fastened to the ground, it is again stable.

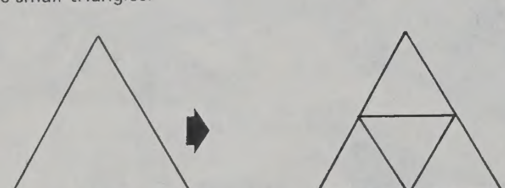
However, if you made a dome this way, the 15 individual triangles would be large, heavy and difficult to lift into place.



Project the icosa onto a sphere and we have

Spherical Icosahedron

We can subdivide the large triangles of the spherical icosahedron to make small triangles:



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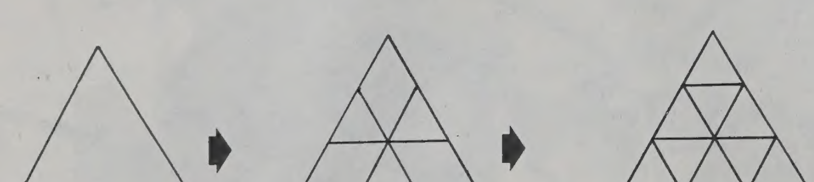
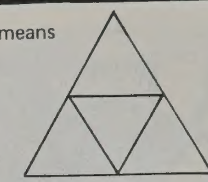
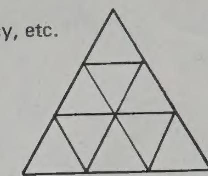


Two subdivisions along each edge means this is two frequency



three subdivisions—three frequency, etc.

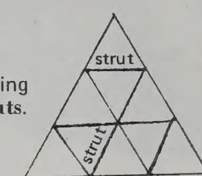


Start calling this a **face** of the icosa.

We'll use 3 frequency as an example, since it's a good frequency for 24-39' domes.

All faces of the spherical icosahedron are equal; thus, if we know the measurements of edge members of one face, we can make a sphere by repeating the pattern 20 times.

Start calling these **struts.**



3 frequency

Geodesics here gives you a set of constants for each strut length so that using these constants, and some multiplication, you can calculate any diameter sphere.

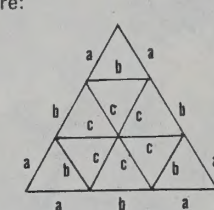
The constants are called **chord factors.**

CHORD FACTORS

A chord factor is a pure number which, when multiplied by a radius, gives a strut length. There are three different strut lengths, A, B, C.

The chord factors for this dome are:

A	.3486
B	.4035
C	.4124



Chord factor times desired radius equals strut length (in some unit of measure). If you want to get the strut length in inches, use inches of radius. For a 24' diameter dome,

Radius is 12'. Convert to inches: 144"

A.	B.	C.
.3486	.4035	.4124
144	144	144
13944	16140	16496
13944	16140	16496
3486	4035	4124
50.1984	58.1040	59.3856

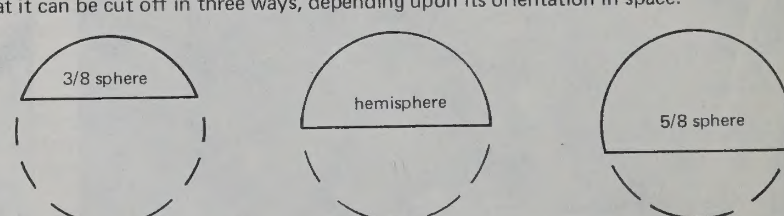
Convert decimals to fractions of an inch. (When you convert decimals to 32nds of an inch, you realize the beauty of the metric system.)

50 3/16"   58 3/32"   59 3/8"

These are strut lengths for a 24' diameter sphere.

If you use hubs, you must subtract for the diameter of the hub.

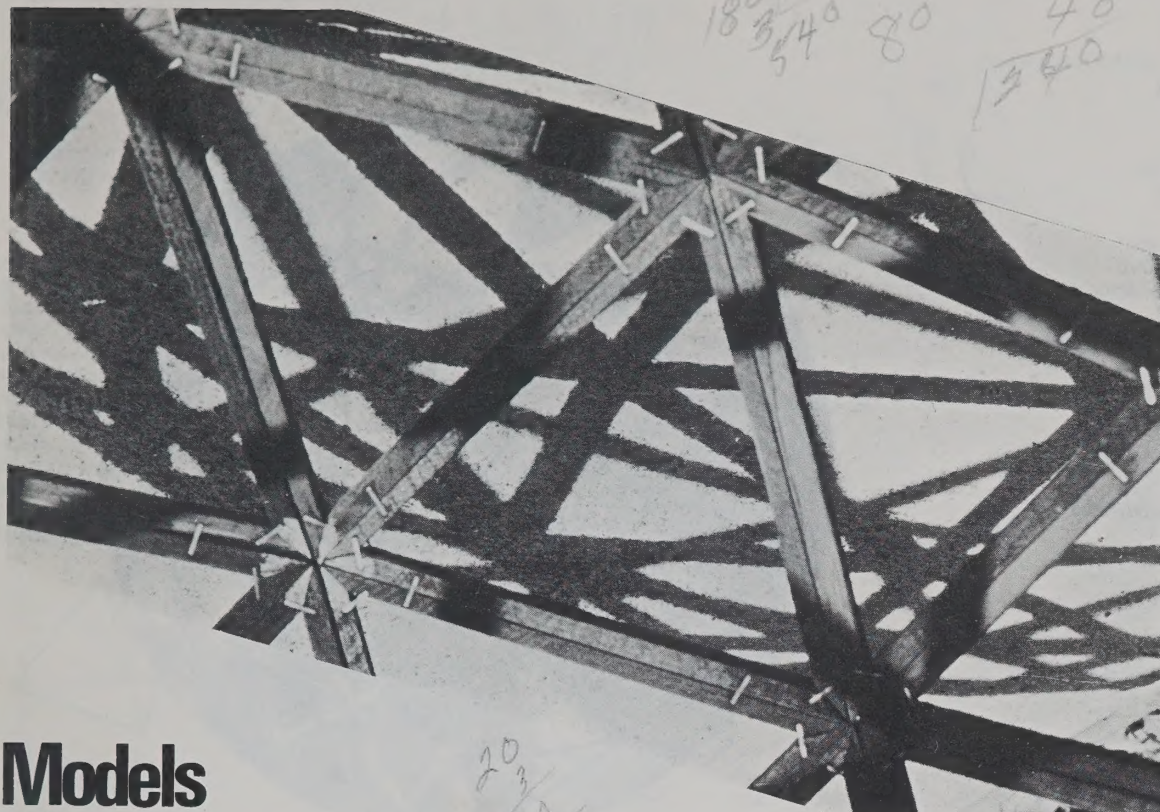
If you make the model of a three frequency sphere (See p.   ), you will discover that it can be cut off in three ways, depending upon its orientation in space:



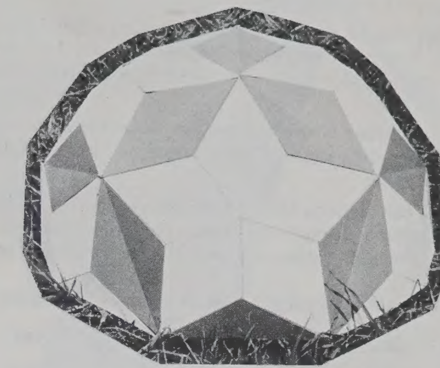
We have just partially explained a geodesic dome that is

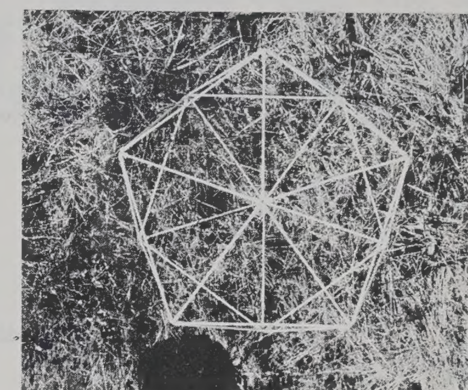
Three frequency
Alternate Breakdown
and generated from an **icosahedron.**

Geodesic domes can be of different frequencies, other breakdowns, and can be generated from other shapes, such as the octahedron or tetrahedron. They can also produce other-than-dome shapes.



20/9 180/108 3 54° 80° 48 1340





Models

20 3 5/60

Models are essential. Don't try to build a dome without first making and studying models. However, don't get so involved with models that you never try a real structure.

You can make many decisions by studying the model, and often save yourself full-scale mistakes by trying it first in miniature.

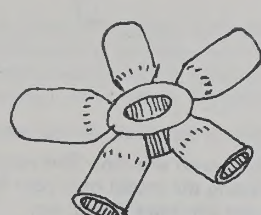
There are two types of models you can easily make:

1) Strut models
2) Membrane models

STRUT MODELS

These are models of the structural framework of a dome, made with 1/8" dowels and "D-Stix" rubber connectors. You can get the connectors from Edmund Scientific Co., 100 Edscorp Building, Barrington, N. J. 08007. Dowels can be obtained at a hobby shop (they are used by model airplane hobbyists) or you can buy one of the D-Stix kits from Edmund, with colored dowels.

To start, get connectors

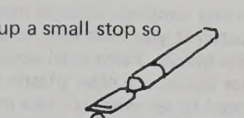


and the dowels—they're 5-10¢ each for 3' sections.

Cut them on a wood board, with X-acto knife. Set up a small stop so that you cut each to exaclty the right length.

Press X-acto blade on dowel, roll dowel, then snap off.

Color code different lengths, put them in glasses.



One of the most instructive things you can do when beginning to learn about structure is to assemble the five *regular solids.* These are the only five polyhedra (a polyhedron is a solid bounded by planes) with all edges of equal length, all faces (planes) exactly the same, all face angles equal, all vertices identical, and all dihedral angles equal.

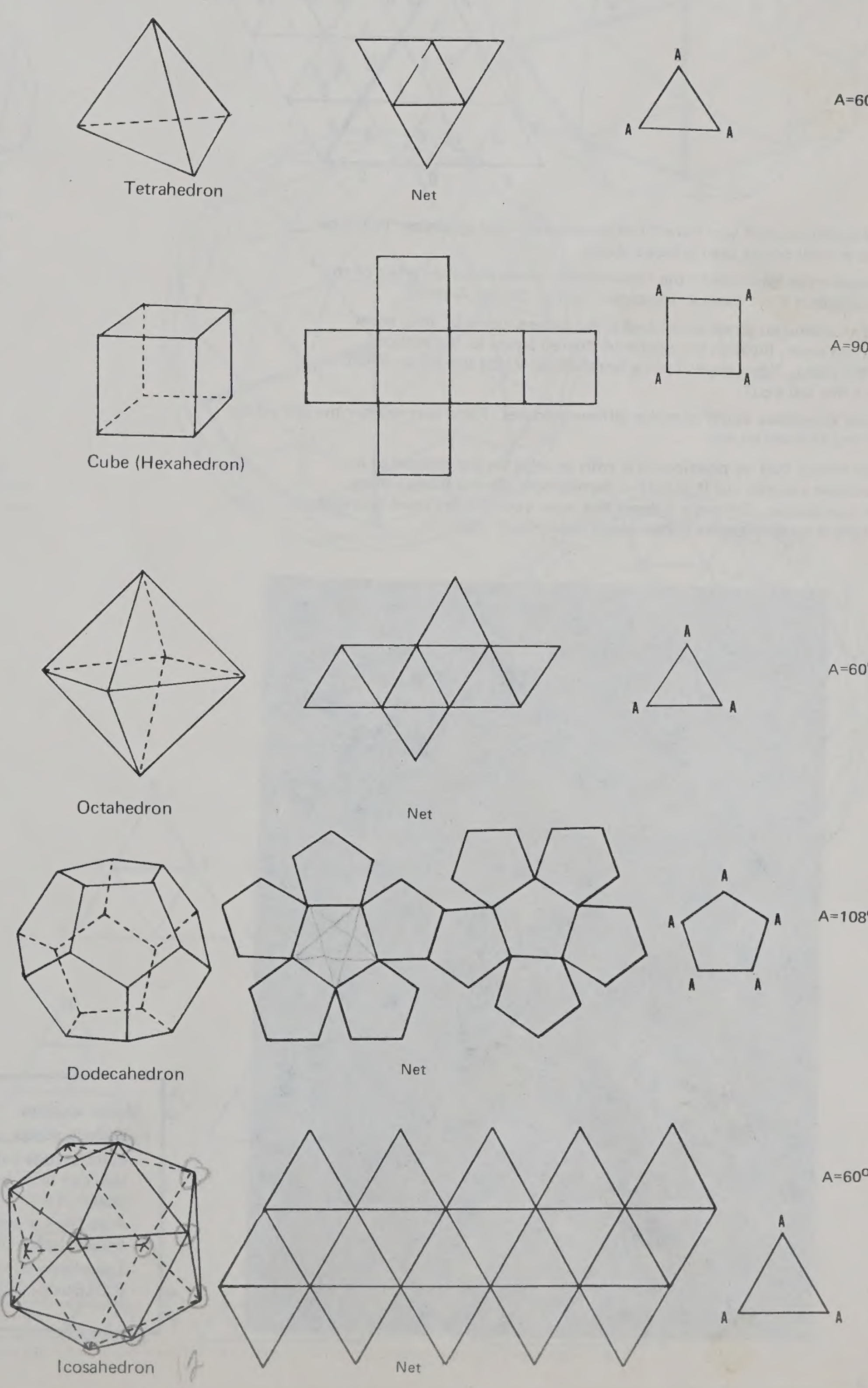
When you assemble these with D-Stix, you are in effect hollowing out each solid, and since you are using flexible connectors you will learn some interesting structural facts.

In the following sketches, the net is the two-dimensional pattern that may be folded to form the polyhedron. Length of strut doesn't matter as long as they are all the same. A=Angle.

Put them together. Notice that the tetrahedron, octahedron, and icosahedron are perfectly stable, even though put together with flexible rubber connectors. Note that the cube and dodecahedron are completely floppy. To stabilize the cube, you must put a diagonal stick across each square; to get it completely stable you find that you have inserted a tetrahedron inside the cube. To stabilize the dodecahedron you must put 5 spokes into the center of each pentagon.

The cube is the basis for 99% of the buildings today. Remove one of the diagonals and see what happens.

Geodesics utilizes the icosa, octa and tetra. The icosa is the basis for most of the domes we have made—you'll see this clearly when you make the models.



600 450 240 1296 12|1296 3|1825 34 5 92 108 12|1296 36 3|168 180

Making a 3-Frequency Sphere

Your first model should be a sphere, since a dome is a portion of a sphere. You can then determine where to cut it off, how to orient it to the earth, and see the relationship of a geodesic sphere to the icosahedron.

Important note: when figuring the length of model struts, be sure you subtract for the length of the connector. In the following table, this has been done.

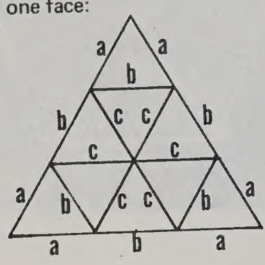
Here are calculations for a 3-frequency sphere. Check these out yourself before cutting, using chord factors below. For ease in multiplying chord factors, the metric system is preferable. Remember to adjust for connector.

Strut	Chord Factor	Length of Strut	Color Code	Make this Many
A	.3486	3 23/32"	Red	60
B	.4035	4 13/32"	Blue	90
C	.4124	4 1/2"	Yellow	120

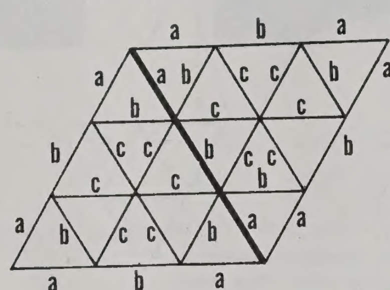
Putting it Together

You are actually making a spherical icosahedron, with its 20 faces subdivided into smaller triangles. Red struts outline vertices of icosa faces.

Put together one face:



Then add another:



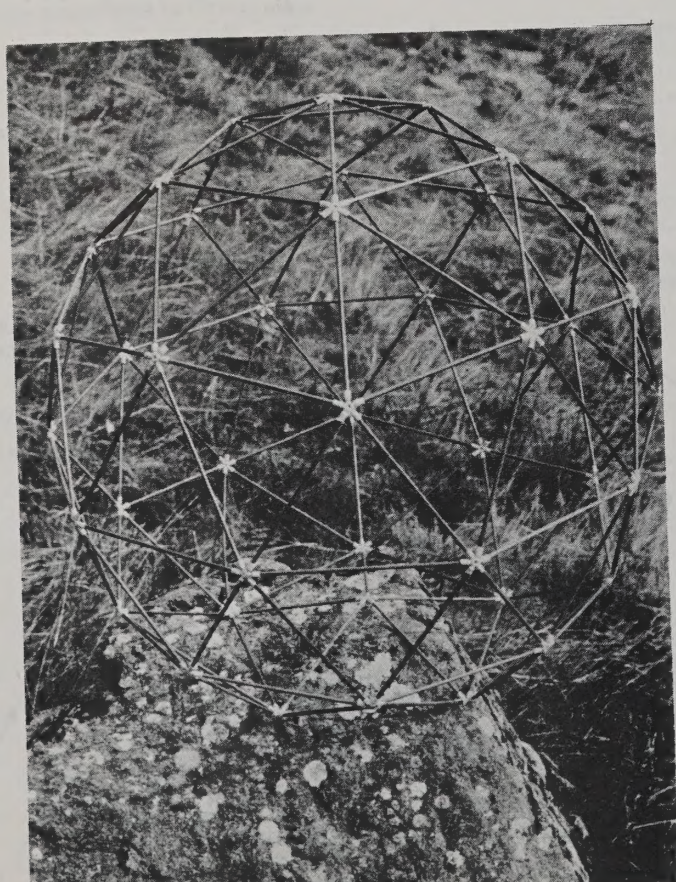
and continue until you have 20 of these subdivided triangles. It will be clearer with colors than it looks above.

Compare the sphere with the icosahedron. Note that the vertex of the icosahedron is the same as the center hub of the red A struts.

Now suspend an icosahedron inside the sphere, using 5" long plain colored struts through the center of the red struts to the vertices of the icosa. You can also put a tetrahedron inside the icosa. What does this tell you?

Study it, remove struts to make different domes. Note that neither the 3/8 sphere nor the 5/8 will sit flat.

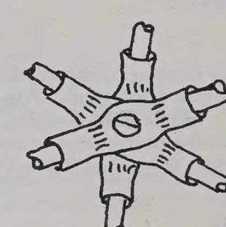
Also notice that by positioning it with an edge on top instead of a pentagon you can cut it in half—a hemisphere. Run a thread along the hemisphere. To make a dome this way, you will cut small triangles in half, 4 small triangles in half along the bottom edge.



Three-frequency sphere with icosahedron suspended inside.

Another type connector is to take pieces of flexible clear vinyl tube, cut in sections, shove dowels in, then put a screw with washers and bolt through the tube.

You get tubing that fits tightly over the dowel. This can be used for bigger than 1/8" dowels, and makes handsome hubs.



MEMBRANE MODELS

These are models of the dome with skin on. This way you get an idea of interior qualities (by holding the model over your head), outward appearance, and where to put windows, doors, etc.

Use a good quality white cardboard. Use a compass to make templates (a template is a master pattern used to mark components).

Using template draw as many components as you need. Cut on a paper cutter if you have one, scissors if not. Put together with masking tape on the inside. Paint with acrylic polymer or white lacquer. Leave openings for doors, use clear plastic (Saran Wrap) for windows. Hold it over your head to see what it's like inside. Take it to the building site and watch the sun's pattern through the windows—this will help you in proper dome orientation.

We made a beautiful model this way using chord factors from Fuller's patent on laminar geodesic domes (see p. 44), creasing diamonds inward along the long axis.

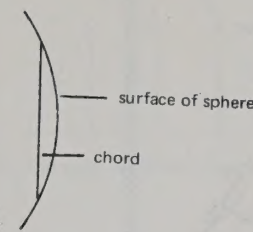
Other models:
—you can string straws together with sewing thread. Difficult, but it makes delicate models
—hot melt glue is useful—it sets up in 30 seconds.

Model supplies:
—styrene sheets, clear rods: Kemtron Corp/P.O. Box 1952/Fresno, CA 93718
—colored rods (ruby, amethyst, robins' egg blue, etc.), double-bubble solution—you can blow bubbles with this that last an hour, for photo and study purposes: Techno Scientific Supply/P.O. Box 191/Baldwin, N. Y. 11510
—Free Dymaxion Maps that fold into icosahedron from Honeywell, Inc./International Division/6620 Telegraph Road/Los Angeles, CA 90022
—Large amounts D-Stix dowels and connectors (service is very slow): Geodestix/P.O. Box 5179/Spokane, Washington 99205

GEODESIC GEOMETRY

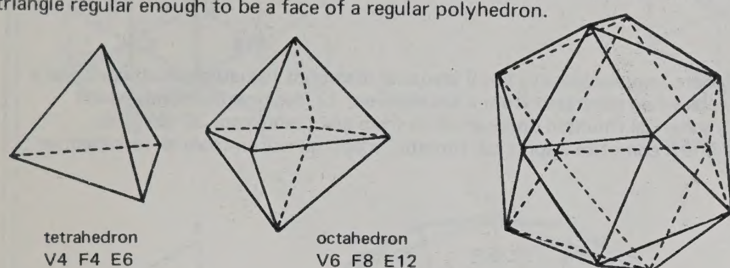
by Jonathan Kanter

The structure of geodesic domes is chords of a grid system of approximate great circle arcs on the surface of a sphere.



A sphere is used as the shape for structures because it encloses the most volume with the least surface area, and doesn't rely on internal structure. The tetrahedron, the simplest polyhedron, encloses the least volume with the most surface area. The sphere is the strongest shape against internal and radial pressure; the tetrahedron against external and tangential pressure. The grid is developed from a basic grid of spherical polyhedra (a polyhedron projected onto a sphere). Regular polyhedra are the best shapes to generate a grid from because they have the most symmetry and regularity. Regular polyhedra are the shapes possible when: all face angles are equal, all edges are equal, all vertices are the same, all faces are the same, and all dihedral angles are equal. A grid with polyhedra composed of triangles is best because a triangle is the simplest polygon, simplest subdivision of surface. An equilateral triangle is the simplest triangle, all edges and angles equal and the only triangle regular enough to be a face of a regular polyhedron.

7 $\frac{7}{16}$
8 $\frac{13}{16}$
9
$24\frac{20}{16}$

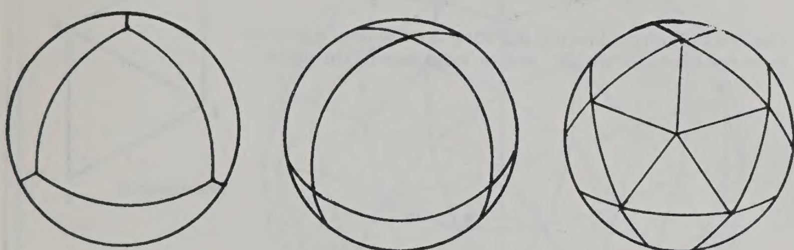


V–Vertex
F–Face
E–Edge

tetrahedron
V4 F4 E6

octahedron
V6 F8 E12

icosahedron
V12 F20 E30

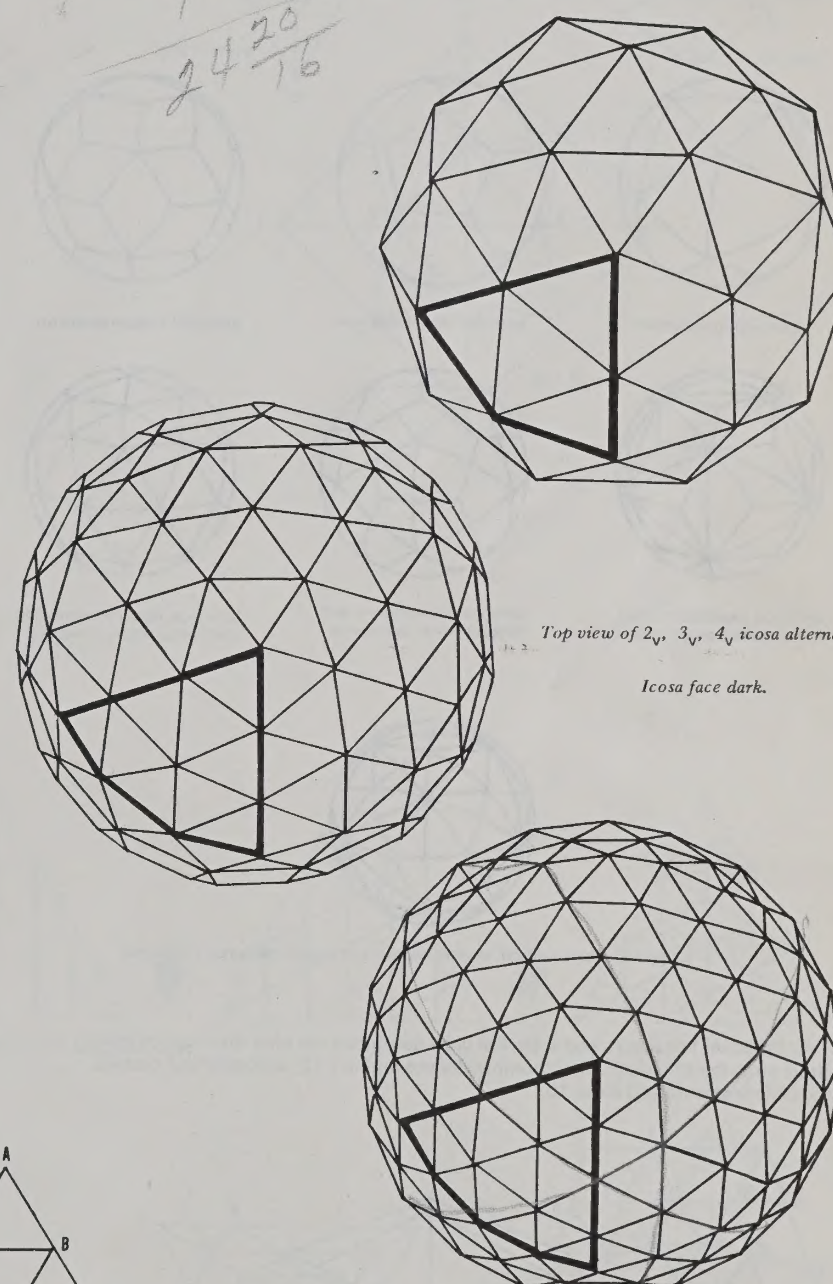


spherical tetrahedron

spherical octahedron

spherical icosahedron

The tetrahedron, octahedron, and icosahedron are three of the five regular polyhedra, whose faces are equilateral triangles. Domes can be developed from all three, with the same frequency, the most spherical from the icosa since it's the most spherical. The grid is developed by breaking down the faces of the tet, oct, or icosa. If the face is broken down so that all triangles are produced and to retain the symmetry of the equilateral triangle, two methods are possible: the alternate and the triacon.



Top view of 2_v, 3_v, 4_v icosa alternate.

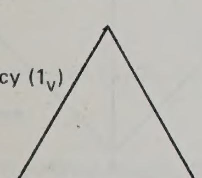
Icosa face dark.

Alternate

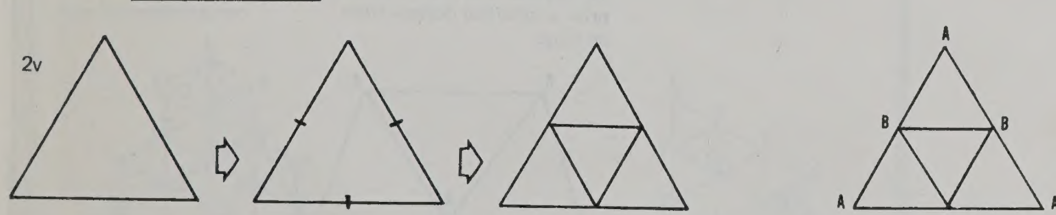
The face is divided by lines (arcs, on a sphere) from each edge to the opposite edge. For any breakdown, as the frequency increases the number of chords and the number of facets increases so the dome becomes more spherical. Frequency is the same as the number of divisions of the edge. In alternate, the divisions are unequal.

All repeating patterns in alternate can be shown in one face (△).
Henceforth, $_v$ = frequency.

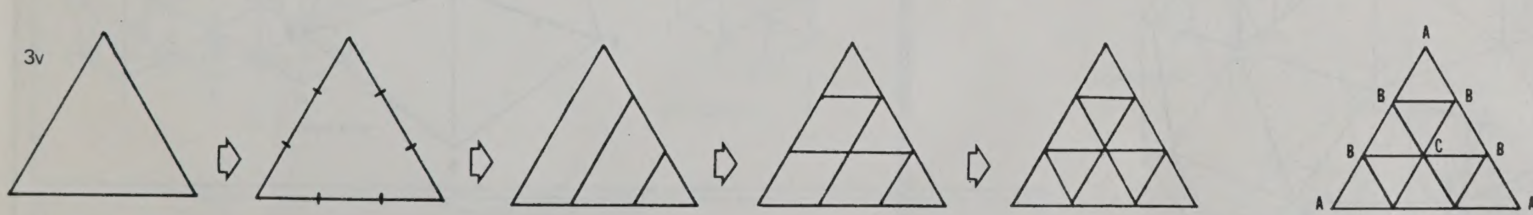
one face
one frequency (1_v)



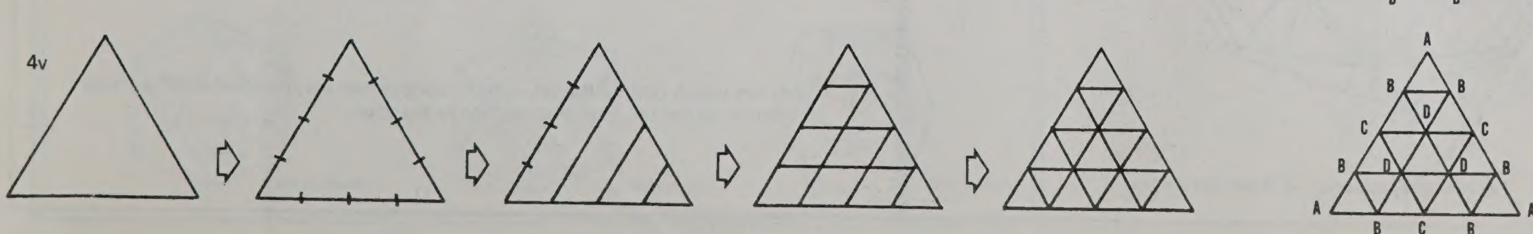
2v



3v

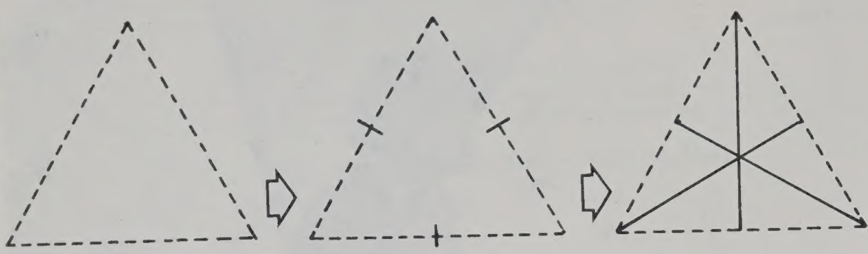


4v

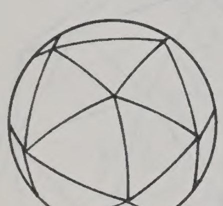


Triacon

The edge of the tet, oct, or icosa is not part of the grid, so is not a structural member in the triacon breakdown. The division of the face is made from the edge to the opposite vertex. The edge is subdivided into equal parts. (Henceforth, edge of face will be dotted.)

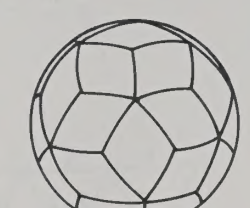


The triacon only works on even frequencies because the divisions must be from the midpoint of the edge to the opposite vertex. The same grid (2_V) is produced by a combination of either a spherical tetrahedron and cube when the grid is developed from a tetrahedron; a cube and rhombic dodecahedron from an octahedron; or a dodecahedron and rhombic triacontahedron from an icosahedron.

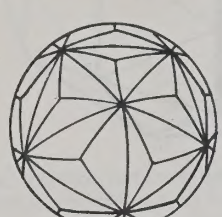


spherical icosahedron

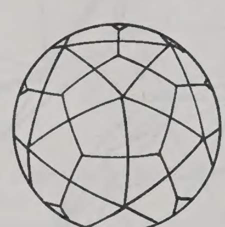
spherical dodecahedron



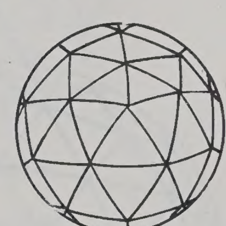
spherical triacontahedron



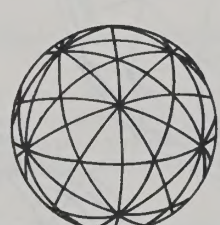
spherical icosahedron and triacontahedron combined



spherical icosahedron and dodecahedron combined

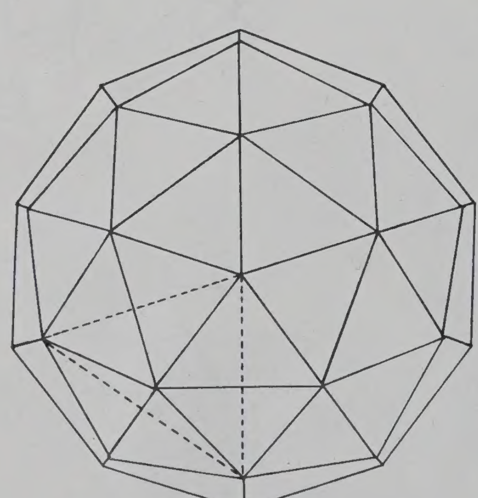


spherical dodecahedron and triacontahedron combined



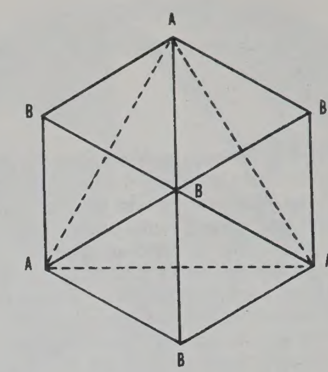
Spherical icosahedron, dodecahedron and triacontahedron combined.

Two spherical tetrahedra and spherical cube combined are nine intersecting great circle arcs; the spherical cube, rhombic dodeca and oct 12; and spherical dodeca, rhombic triaconta and icosa 15.



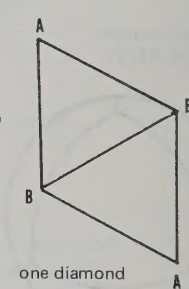
Top view of 2_V icosa triacon. Icosa face dotted.

The triacon breakdown has three repeating patterns. It is symmetrical, so for 2_V:



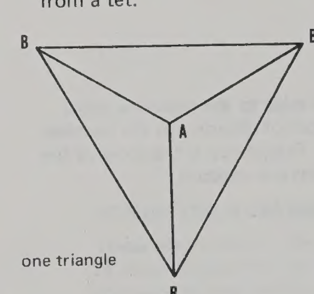
A whole sphere (any frequency) has 6 identical diamonds (squares) which comprise a spherical cube when generated from a tetrahedron; 12 identical diamonds which comprise a spherical rhombic dodecahedron from an octahedron; 30 identical diamonds which comprise a spherical rhombic triacontahedron from an icosahedron.

The lines which outline the diamond are the lines which go from the center of the tet, oct, or icosa face to the vertex.



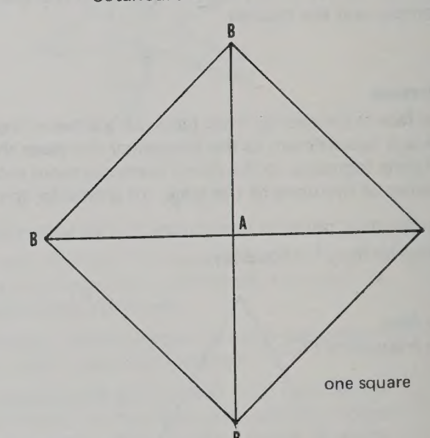
one diamond

The sphere has 4 identical triangles which comprise a spherical tet when generated from a tet.



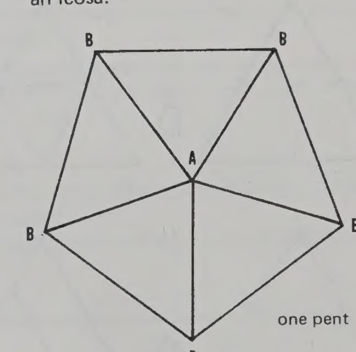
one triangle

6 identical squares which comprise a spherical cube from an octahedron.



one square

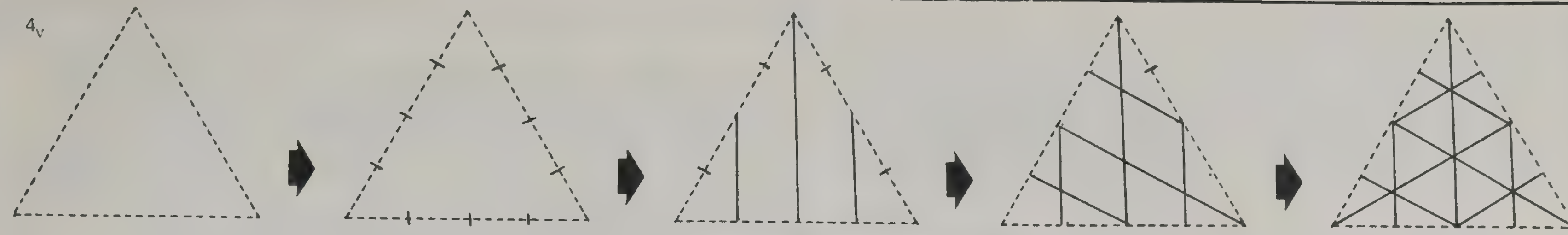
12 identical pents which comprise a spherical dodeca from an icosa.



one pent

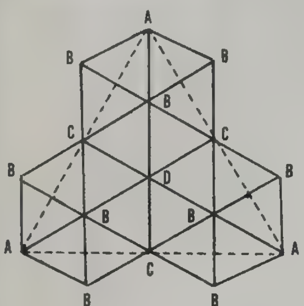
The lines which outline the tet, cube or dodeca face are the lines which go from the center of the tet, oct, or icosa face to the edge.

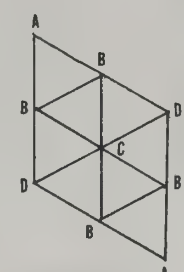
4_V



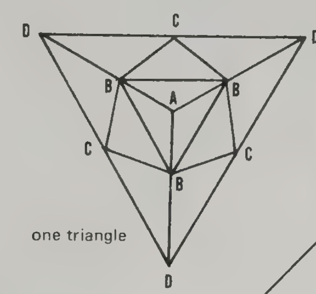
For 4_V the edge is divided into 4 equal parts.

4_V has 4 different lengths, AB=BC.
It is symmetrical so:

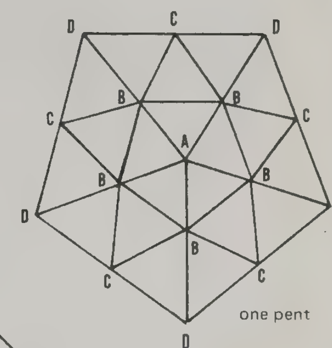




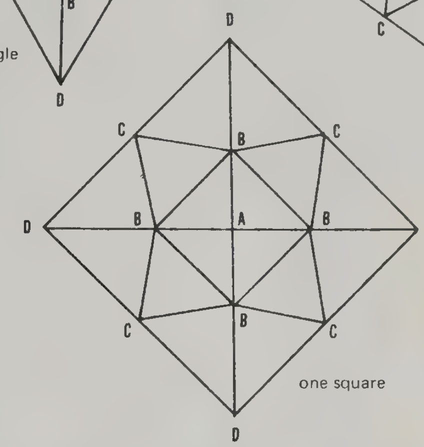
one diamond



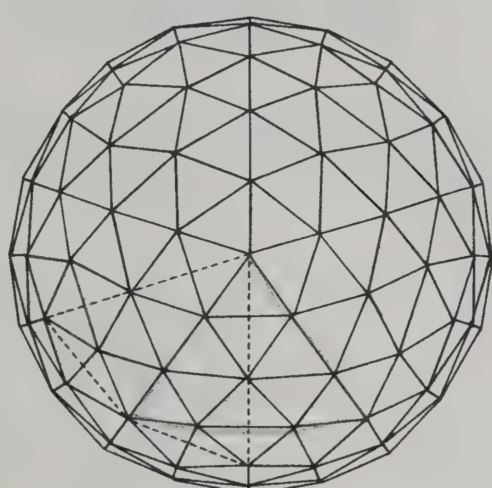
one triangle



one pent

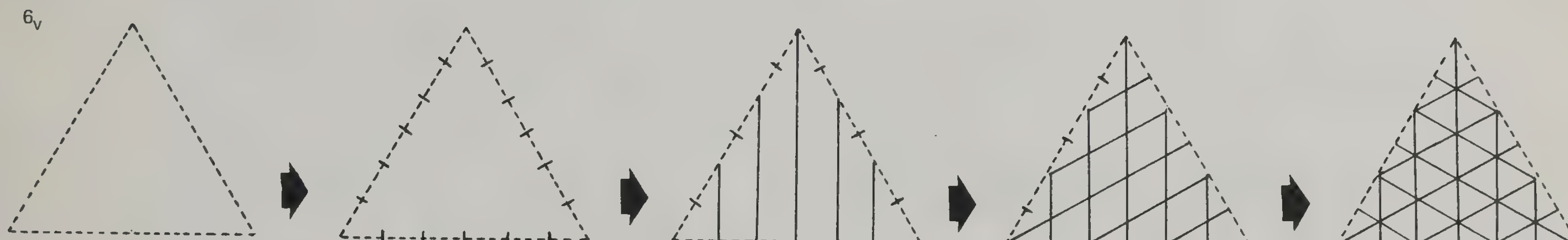


one square



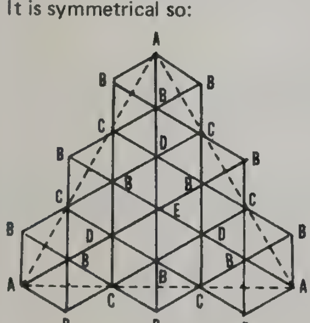
Top view of 4_V icosa triacon. Icosa face dotted.

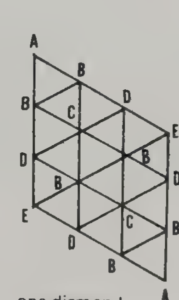
6_V



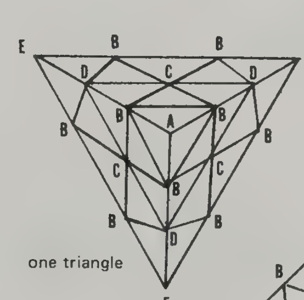
For 6_V, the edge is divided into 6 equal parts

6_V has 6 different lengths, AB=BC.
It is symmetrical so:

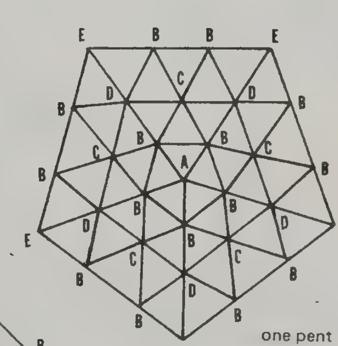




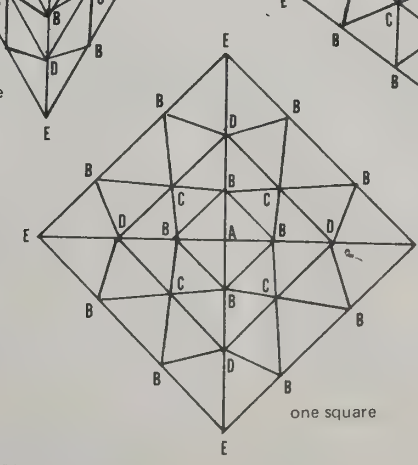
one diamond



one triangle

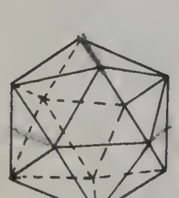


one pent

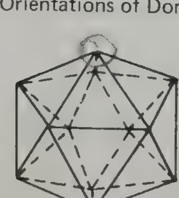


one square

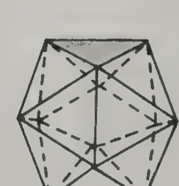
Orientations of Domes



edge zenith



vertex zenith

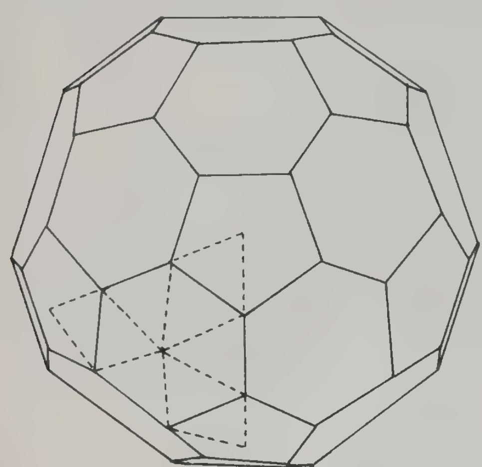


face zenith

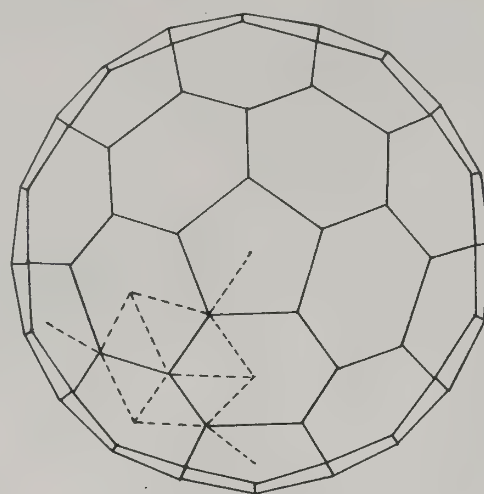
GEODESIC GEOMETRY *continued*

It is possible to modify or distort domes, with some loss in strength. The struts inside the hexagons and triangles, squares or pentagons can be removed making flat hexes and triangles, squares or pents. The symmetry is the same as with all triangles. When removing struts to form hexes and triangles, squares or pents with alternate, you have to use frequencies with a point in the center of the tet, oct, or icosa face; with triacon, any frequency works.

Or 2 triangles can be grouped together to form diamonds. The symmetry is the same as with all triangles. With alternate there must be at least a 3_V, and the patterns are symmetrical only with a point in the center; with triacon, any frequency works.

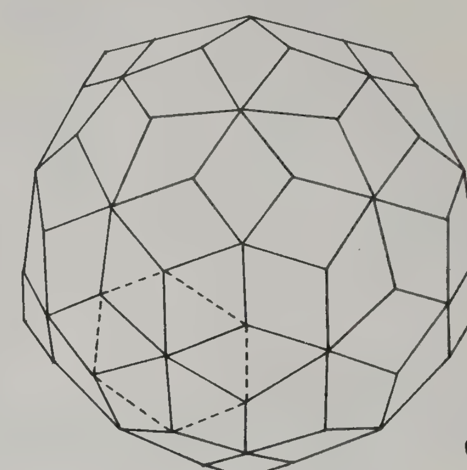


Top view of 3_V icosa alternate.
Removed struts from one face dotted.

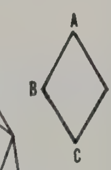


Top view of 4_V icosa triacon.
Removed struts from one face dotted

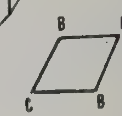
It has two different diamonds:



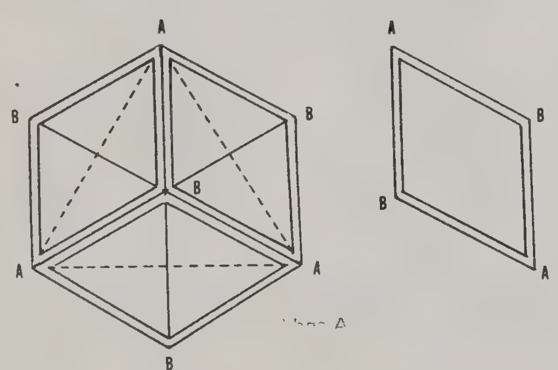
Top view of 3_V icosa alternate.
Removed struts from one face dotted.



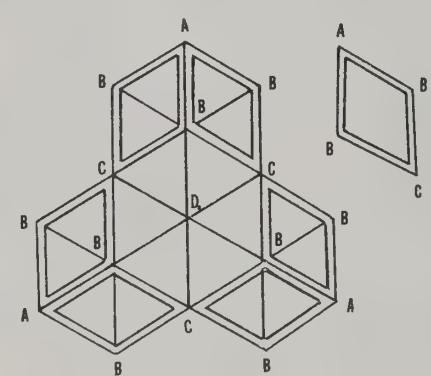
and



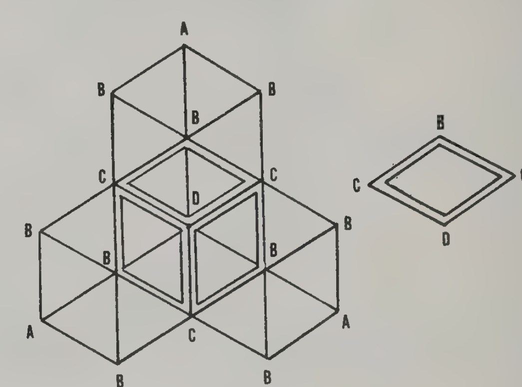
For 2_V triacon you use the outlined diamond:



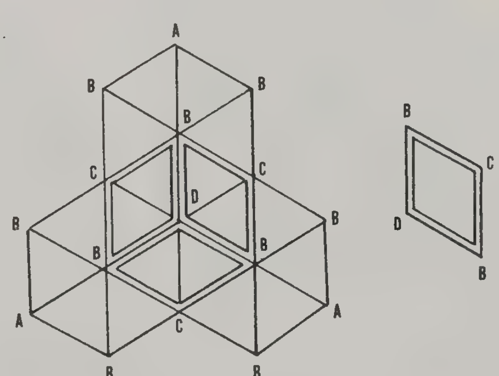
For 4_V triacon you use this diamond:

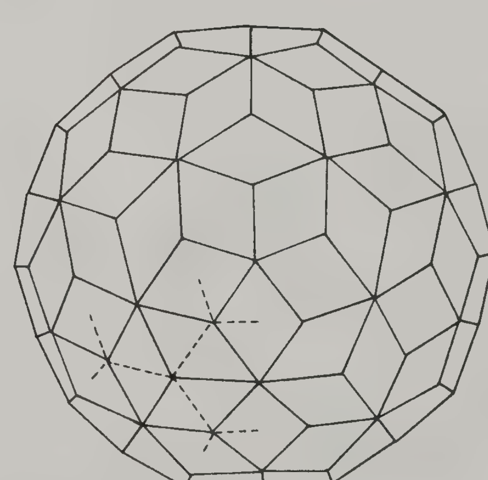


and this diamond:

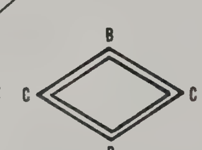


or this diamond:





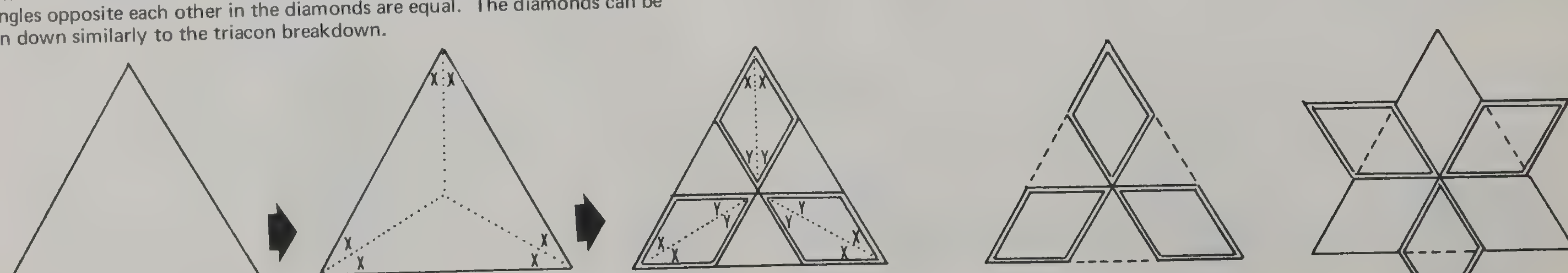
Top view of 4_V icosa triacon (with diamond



)
Removed struts from one face dotted.

Fat Diamond/Thin Diamond

The face can also be broken down by a different method to produce fat and thin diamonds. The diamonds have the same edge lengths but different face angles. The angles opposite each other in the diamonds are equal. The diamonds can be broken down similarly to the triacon breakdown.



So x=y and all edges are equal

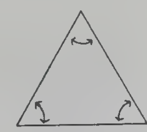
fat diamond

thin diamond

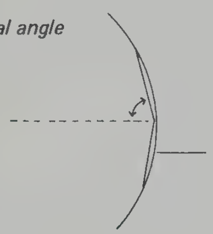
Basic Information

Chord factor multipled by radius equals strut length (because of constant relationship between the radius and the length of struts).

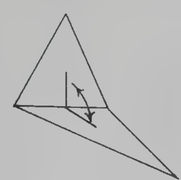
Face angle between struts or arcs on the face of a polygon



Axial angle



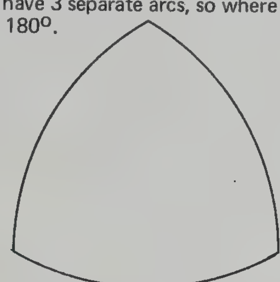
Dihedral angle between panels



Spherical Trig

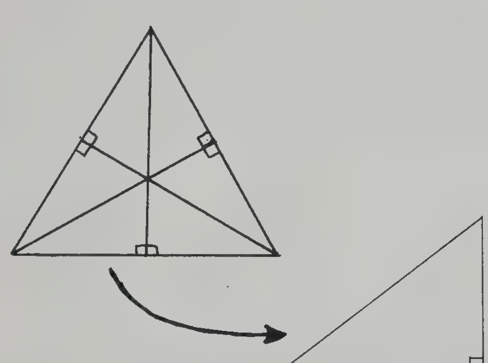
by Jonathan Kanter

Spherical trigonometry is about spherical triangles—triangles made up of arcs on the surface of a sphere. Because of the curvature of the sphere (positive curvature), the angles of a spherical triangle will add up to more than 180°. The amount over 180° is called the spherical excess. The sum of the angles will also be less than 540°, because a spherical triangle has to have 3 separate arcs, so where the arcs intersect (the vertices) the angle will be less than 180°.

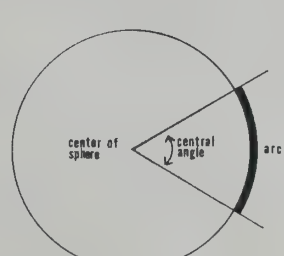


Equilateral spherical triangle.

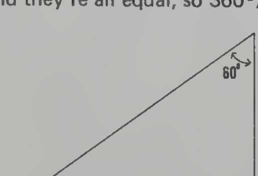
Spherical trig is used to calculate chord factors and angles. To calculate them you use a spherical right triangle, one of the six identical right triangles formed by the triacon breakdown.



Degrees are used to measure the arcs too, because the arcs are measured by their central angle.



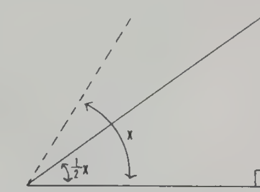
The angle made by the arcs that intersect at the center of a face will be 60°, because there are 6 angles there and they're all equal, so 360°/6 = 60°.



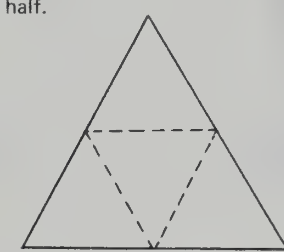
The angles of the right triangles formed at the vertices of the face are either 60°, 45° or 36°: in a spherical tet, 3 faces come together at the vertices (360° around any vertex), so 360°/3 = 120°, and the lines from the center of the face to the vertex bisect the 120° angle, so 120°/2 = 60°;

for the oct, 360°/4 = 90°, 90°/2 = 45°;

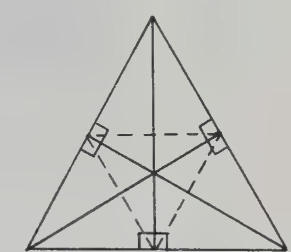
for the icosa, 360°/5 = 72°, 72°/2 = 36°.



A great circle that bisects the edges of a spherical polyhedron is called an equator. An equator crosses the faces of a polyhedron equally. It crosses half the faces. So for a section of the equator passing through the face of a tet (since it has 4 faces, 2 is half; 360° is a complete great circle) 360°/2 = 180°. For an oct, 360°/4 = 90°. For an icosa, 360°/10 = 36°. The right triangles cut the 1/2, 1/4 or 1/10 of the equator in half.



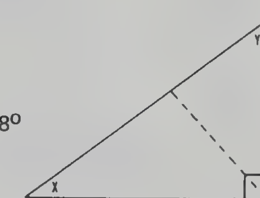
The dotted lines (equators) are 1/2, 1/4, or 1/10 the whole equator.



The section of the dotted lines (equators) passing through a right triangle is 1/4, 1/10 or 1/20 of the whole equator.

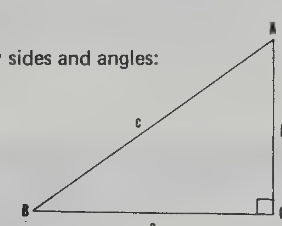
All the information without calculation is:

Y = 60°
X = 60°, 45° or 36°
Dotted line is 90°, 45° or 18°



The other variables can be calculated because any 2 variables will determine a right triangle, which has a right angle and 5 variables.

To identify sides and angles:



C is always the riaht angle.
A and B can be interchanged.

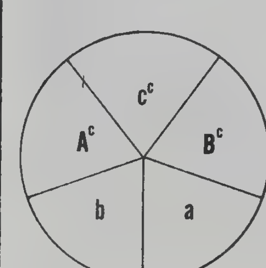
To solve a right spherical triangle, Napier's rules are used.

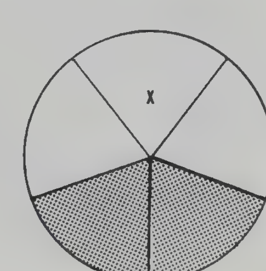
Rule 1: the sine (of any part) = product of cosine of the opposite parts

Rule 2: the sine (of any part) = product of tangents of the adjacent parts

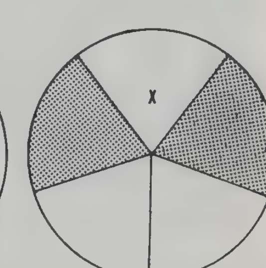
When using Napier's rules you use logarithms. Adding logarithms is the same as multiplying.

The triangle can be put into an easy form for computation. The sides and angles are related in the same way as in the triangle. The right angle which is always the same can be omitted. The small c means to use complementary functions.





opposite case

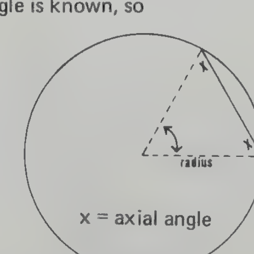


adjacent case

Chord factor = 2 times the sine of $\frac{\text{angle}}{2}$.

For axial angles, construct an isosceles triangle with radii as two of the sides, and the chord in between as the third. The central angle is known, so

$$\frac{180^\circ - \text{central angle}}{2} = \text{axial angle.}$$



For planar face angles: find the spherical excess for the whole triangle (all the angles − 180°), divide by three, then subtract the result from every vertex.

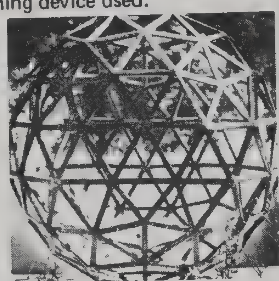
SunDome

The sun dome is a logical next step after model making; it's like making a full scale model. It is cheap, lightweight and easy to construct.

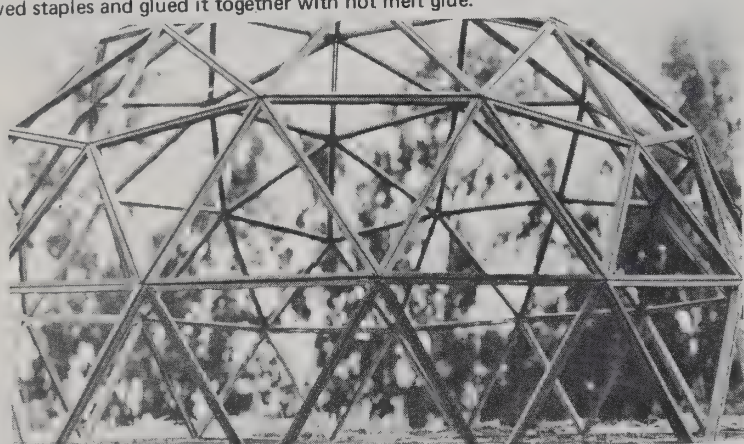
Sun dome plans were originally published in the May 1966 issue of *Popular Science*. The plans were then improved and blueprinted and are available for $5. from

Popular Science Monthly
355 Lexington Avenue
New York, N. Y. 10017

For the fee you receive clear and simple instructions (as well as a license to construct one dome) for making a 3-frequency 3/8 sphere, polyethylene skin greenhouse or swimming pool cover. A simple system: two triangles make the entire dome and a hand stapler is the only fastening device used.



When I first got the plans, I made a model of D-Stix. Next, this 1-meter-diameter sphere from redwood scraps ripped on a table saw. I first put it together with staples, then removed staples and glued it together with hot melt glue.



Then I made this 8' dome, again of redwood scraps put together with staples. It didn't take too long, and I learned a great deal by being able to get inside it. I covered different triangles with cardboard, testing different window patterns.

The next thing I tried was this 4-meter vinyl-skinned dome. It differs from the Sun Dome plan in that it has an extra course of triangles at bottom, making it a 5/8 sphere rather than 3/8; and it is bolted rather than stapled together. We used it for a greenhouse, for guests, and for watching stars on clear nights. It was on our hillside in Big Sur. When you climbed to the top of the ridge, about 1/2 mile, it looked like a soap bubble.

Order the plans and then consider the following modifications which we have worked out over the past year. A good reason to get the plans is for the clear diagram of putting together a 3-frequency dome. Also, if you do not want to get involved figuring chord factors, sizes are given for making 16 1/2', 25' and 30' domes.

Making 3/8 sphere or 5/8 sphere

Make the model described on page 6 and decide if you want to make a 5/8 sphere rather than the 3/8 sphere specified in Sun Dome plans. If you make a 5/8 sphere, the dome will be much more spacious, you will use 40% more materials, and must make 30 additional large triangles which will make up the bottom course. Neither a 3/8 nor a 5/8 sphere will sit flat (see page19).

Strut size: The 1/2" x 3/4" strips (actual measure) as recommended may be too light, especially with the 30' dome. Jay recommends 3/4" x 1" true measure. (A "two by four" actually measures 1 1/2" x 3 1/2" Use knot-free wood. Douglas fir has high tensile strength. The deeper dimension is perpendicular to the interior-exterior of the dome, and the smallest dimension is parallel to the dome membrane.

Strut shape: If you build the dome according to plans, with regular rectangular wood strips: 

you will have a gap when you put it together: 

(See opposite page: "Ripping")

If you want struts to fit together tightly, 

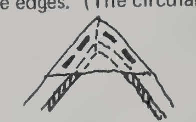
rip to a 7° bevel on a table saw. Purchase wood twice the depth of the strut size desired. If you want struts 3/4" x 1", get

 and rip  getting 

Important: When you later cut the end angles on these, remember that with A's and C's there will be a right and left side to each triangle. Look at the plans and drawings of right and left triangles to see this clearly. With B's, where both tip angles are the same, it doesn't matter.

Tip angles: These should be cut with a jig (see page16). Jigs should be marked so that you can see if they move while you are using them. Cut struts to length first, then cut tip angles. *Remember that if you bevel, there are rights and lefts for A's and C's.*

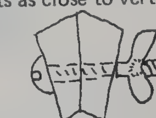
Reinforcements: For greater strength—and especially if the dome will be put up and down often—add triangular braces in the corners: either light metal or 1/8" tempered Masonite glued and stapled to triangle edges. (The circular braces shown in the Sun Dome plans don't work too well.)



These will also prevent the dome from falling apart due to wind fatiguing the staples at vertices.

Fasteners:

a) *For easy portability:* bolt dome together with wingnuts, rather than staples: three bolts per strut with washers at both ends. Try to get the end bolts as close to vertices as possible. If you use bolts, bevelled strut edges are essential.



b) *Pneumatic staples:* Jay made a dome this way, renting a Bostitch staple gun that shot 3/4" x 1" rustproof staples. A backup man outside the dome holding a long stick with padded brick tied to the end is necessary for opposing the kick. Panels are held together with welders' clamps, especially useful if skin has tightened, bowing in the struts. This makes a Sun Dome much more wind-resistant, as the strong lifting forces generated by high winds tend to pull out staples. Small rustproof staples are still used for putting skin on frames; the big gun is used only for assembly. Be careful—the gun is lethal. Bevelled struts are not essential with this method. It is almost impossible to remove these staples, so the dome becomes more or less permanent until demolished.

Staples: Use only rustproof staples. If you use a Duofast gun, get their Monel staples.

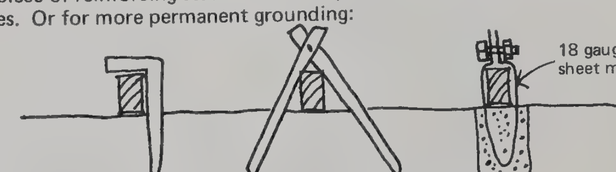
For other than polyethylene skins, see page 53.

Floor: If you do not have a water-impervious floor, the interior of the dome will have a heavy layer of condensation. Since the dome diameters given in Sun Dome plans are not precise, don't make a floor until after the dome is assembled.

Color code sticks as you make them, same colors as the model. A's red/B's blue/ C's yellow. Color at tips with a board across struts to get a straight line. Spray paint works well.

Make *extra parts* in case of breakage, also because you may have to custom-make the last triangle if there has been accumulated error.

Staking: *Stake down dome securely as soon as first course is completed.* The most common catastrophe with sun domes is to see them sailing across a field. You can bend over a piece of reinforcing steel into a J-shape or drive two pieces of pipe in at cross angles. Or for more permanent grounding:



Do the staking on the inside to prevent wind from kicking in lower end.

Jay recommends *painting struts black* with fire-retardant paint. Black protects the skin from double dose of sunlight as it does not reflect, and the sun does not bounce back into the clear plastic. It also doesn't show water stains.

Putting it up: Better than the central pole shown in plans is to have a few friends hold long sticks with forked ends to support the panels as they are being fastened together. After you finish the second course, the dome will start supporting itself. The dome must be on flat ground or it will be difficult to assemble.

Stapling skin to frames: Staple every 3". Wrap skin around three sides of strut, then staple. If you staple skin on in warm weather it will contract (tighten) in the cold. If it is very warm, don't stretch the skin too tightly as it may pull things apart when it is cold.

Waterproofing seams: Vulkem sealant might work (see page34) or tape with "silo tape", available in farm stores, or vinyl electrical tape. Black lasts longest. Tape should be at least 2" wide. Tape will greatly increase the dome's ability to resist wind lift forces pulling out staples.

Vents: Make some at top, into and away from prevailing winds; and some at floor level. You can do this by unstapling a panel, hinging one edge, and taping over the edge for waterproofing. Waterproof two other edges by stapling thin aluminum flashing strip that overlaps neighboring panels several inches, bent to fit. Do not make vents or doors in a way that leaves two adjacent triangles open, or you will weaken dome. See living hinge, page 53.

Following is part of a letter I received from Jay last year on sun domes:

"Our 25-footer was constructed from scratch by 20 untrained people in 14 hours, weighed 112 lbs, cost $52. Our 35-footer with double skin was fabricated in 7 hours and erected in partial darkness by a varying crew of drunks in about 18 hours. I think there is an easily worked out ratio between the skin area and cost of materials."

Big Sur Dome

These are details of an eight meter (26' 3") diameter dome I built in Big Sur in 1969. Skin is plywood, with clear vinyl pentagons, making five large pentagonal windows around the sides, and one clear pentagon at top center for stargazing.

It is a panel frame dome; two different size triangles and four different struts make the entire structure. Using bigger struts and thicker plywood, you could probably build up to a 40' dome using this 3-frequency geodesic pattern.

The greatest advantage of a bolt-together dome such as this, as compared to the hub system wooden dome, is portability. When we left Big Sur, I sold the dome—it was disassembled and moved. The dome weighs less than 3,000 lbs and can be transported in a flat bed truck.

By designing and fabricating a portable structure you will realize a great degree of freedom, not possible for the permanent, stay-in-one-place house builder. It may mean that you do not have to buy land. With the prospect of packing up your house and leaving, you might be able to lease land for a two year period, or get permission to put your dome on someone's land in exchange for caretaking. We generally think in terms of a shelter being permanent and immovable, because houses are too heavy, and made of many thousands of different components. However if you do build a dome, and it sits lightly on the land, and if it can travel, you can leave the land as you found it.

VITAL STATISTICS

Geometry: 3-frequency geodesic, 5/8 sphere, icosa-alternate breakdown, vertex zenith

Diameter: 8 meters (about 26' 3")

Floor area: 530 square feet. (Even though struts are measured metrically, other dimensions are still in feet as comparisons with other structures are inevitable.)

Surface area: 1371 sq ft

Volume: about 6100 cu ft

Lineal feet struts: 1638'

Weight: large triangles: 28 lbs each
small triangles: 10 lbs each
total: 2400 lbs

DOME INGREDIENTS

Frame & Skin

—30 pieces 3/8" "Duraply" plywood—4' x 8' sheets
—about 1700 lineal feet strut material (*after* ripping to bevel)
—3 rolls 48" x 50' vinyl. The 48" just makes it as covering for small triangles.
—30 lbs hot dipped galvanized 4d or 6d nails
—20 tubes waterproof construction adhesive
—1 box 5000 Monel (rustproof) 1/4" Duo Fast staples
—enough caulk and/or tape for about 800 lineal feet joints
—500 1/4" diameter galvanized bolts. Length of bolt depends upon total width of bolted-together struts. I used 3 1/2" bolts for 3" struts

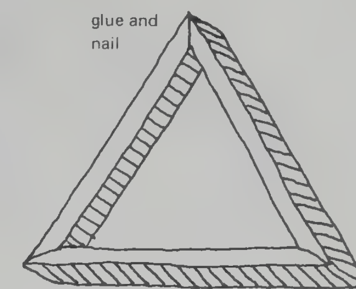
Concrete floor

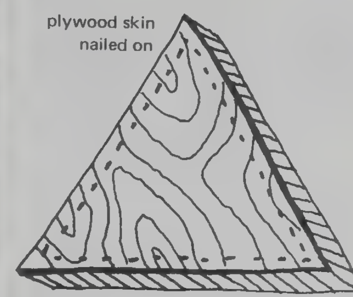
—5 yards sand & gravel
—20 sacks cement
—30 8 1/2" anchor bolts
—500' 6" x 6" steel mesh
—500 sq ft polyethylene
—about 90 lineal feet 1/2" reinforcing steel

In describing how it was built I'll use the same strut designation as do the Sun Dome plans (A, B1, B2, C) to avoid confusion. If you are going to build this type of dome, you should buy the Sun Dome plans (see page 12) as the blueprint may answer some points not covered here. Be sure you make a model first.

BUILDER'S INSTRUCTIONS

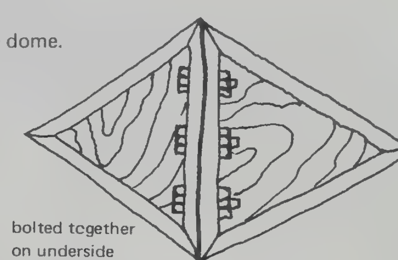
First, struts are cut, then put together





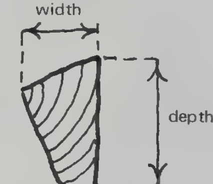
Then plywood is cut, and attached to triangle

Then panel frames are bolted together to make dome.



Cutting Struts

Size: A strut has depth and width. Depth is perpendicular to interior-exterior of dome; width is parallel to dome membrane.



With wooden domes, depth should be greater than width, as plywood is girdled around the dome, providing lateral support, while the depth of the strut provides the strength for in and out forces.

Fuller has stated that wood frame domes should have a ratio of 24/1, strut length/strut depth. Since the longest strut in an 8 meter dome is 165.0 cm (65"), this ratio would produce a strut about .68 cm (2 7/8"). Therefore, the lumber you buy (before ripping—see below) should be—actual measurement—at smallest 1 1/2" x 2 1/2", at largest 2" x 3". *Actual measurement* is what it reads on your tape measure, not what the lumber company calls it. What is known as a "2 x 3" is actually 1 5/8" x 2 5/8", etc.

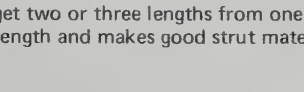
In Big Sur I had some 16" x 16" redwood bridge timbers ripped into 3" x 3" at a local lumber yard. This was my first mistake, as I should have had them milled to precise measurements. When lumber is merely ripped, and not run through a planer, there are sometimes 1/4" discrepancies in width. This will give you frightful headaches when trying to cut to length, as each piece is at a slightly different distance from the fence on the ripsaw table. Use lumber for struts that is of precise measurement.

Buy your lumber so that it can be cut up with little wastage. Calculate the correct lengths to order (lumber comes in even numbered 2-foot increments), decide whether to get two or three lengths from one piece. Douglas fir has very high tensile strength and makes good strut material.

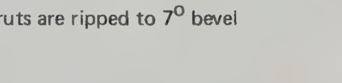
First step: Ripping

So that panels when assembled fit together tightly, struts are ripped to 7^{o} bevel

so they fit like this



If you don't bevel they'll be like this



I discovered this when I put together a little 8' dome with staples—I hadn't thought of it before. An example of why model making is invaluable, and can prevent full scale errors.

You'll need a table saw. Set it at 7^{o} and rip all strut material. Sharpen the blade frequently. Don't overwork the saw's motor. This is a lot of ripping. Wear goggles and make sure each piece is tightly against the fence. Have a helper pull the wood through. Make sure you rip exactly in the middle.

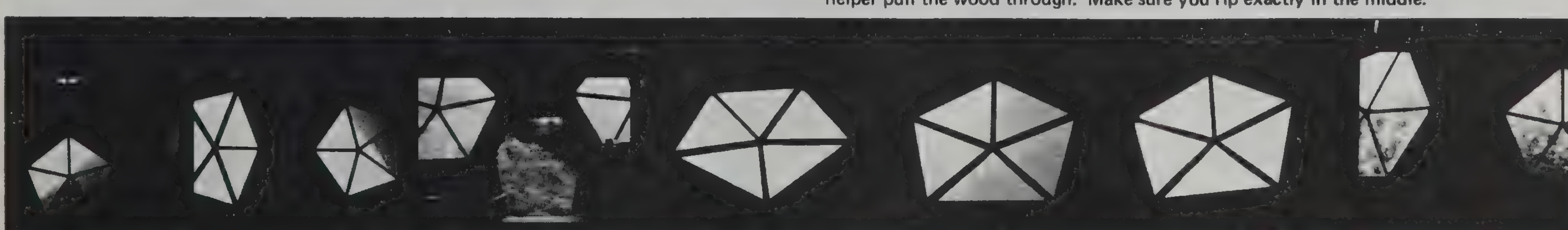


Table of Struts

Cut struts in this order, after they are bevelled; for working in meters, get a metric tape measure from a drafting store.

Strut	Number to Cut	Length	Rip to Bevel of	Tip Angles
A	15 rights 15 lefts	139.4 cm (54 15/16")	7°	35° — 27½°
B1	30	161.4 cm (63 9/16")	7°	27½° — 27½°
C	80 rights 80 lefts	165.0 cm (65")	7°	30½° — 30½°
B2	80	161.4 cm (63 9/16")	7°	29° — 30½°

Second step: Cutting to Length

Important: Both small and large triangles have a *right* and *left* side (A's and C's) if you bevel struts. Therefore when cutting A's and C's to length, you will cut 50% *wide side up*, 50% *narrow side up*.

Start with sticks stacked in three piles. Cut each strut an inch or two longer than final length so that they are easy to maneuver. Allow yourself more margin if you wish.

Once the angle is set, cut all pieces you have to that angle.

Cut enough extras to make up for mistakes.

You'll need a radial arm saw. This tool is designed for cutting many pieces of wood to the same length. This is about the most important step in building this dome. A very small error in strut length will throw the entire triangle hopelessly off. Have a helper check each piece against a master piece as you cut, so stop does not creep.

All the struts and plywood for the Big Sur Dome.

Shop Yoga

If your radial arm saw guage is such that a cut at 90° to the piece of wood you're cutting reads 0° on the guage, the angle you set should be the complement of the tip angle. Since our saw's guage was like this, here is how we cut struts.

A – 62 1/2° – first cut

Set saw for 62 1/2°. Cut 50% of A's broad side up, 50% narrow side up, trimming a little off the end. Stack in two piles.

B1 – 62 1/2° – first & second cuts

Cut one end of all B's.
Set stop for B's at 161.4 cm (63 9/16"), turn over and cut other end to length.

Color code B's—one blue stripe in middle—narrow side.
Stack in two piles.

A – 55° – second cut

Set saw for 55°. Set up stop for A's at 139.4 cm (54 15/16"). Cut 50% wide up, 50% narrow up.

Color code 55° tips of A's red.
Stack in two piles.

C – 61° – first cut

Set saw at 61°. Cut 50% wide up, 50% narrow up. Stack in two piles.

C – 59 1/2° – second cut

Set saw for 59 1/2°. Set stop for C's at 165.0 cm (65")
Cut to length. 50% wide up, 50% narrow up.
Color code 61° ends of C's yellow.
Stack in two piles.

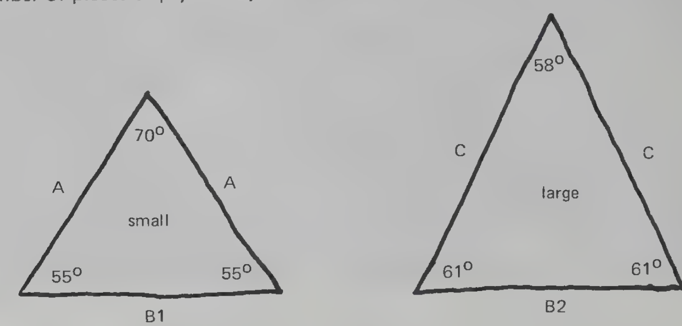
B2 – 59 1/2° – first and second cuts

Cut 59 1/2° end of B2's.
Set stop for 161.4 cm (63 9/16").
Cut other end. Be sure to flip for second cut.
Color code B2's—two blue stripes middle.
Stack in two piles.

Drilling Struts for Bolts: You can drill struts now by making a jig. Or you can drill as you put up the dome. If you jig drill, make holes 1/16" oversize to allow for errors.

Putting Frames Together: I used glue at the tip ends, and 16d threaded nails, which have five times the holding power of ordinary nails. Hot dipped galvanized nails work well too, as they have a rough barbed-like surface. If your struts have been cut correctly, each frame will be exact.

Cutting Plywood: See p. 18 on jigs. There are 30 small triangles, 75 large triangles in the 5/8 sphere. If you want the bottom course triangles to extend over the floor's edge (highly advisable) for water run-off, you will have 45 large triangles, and 30 *extra*-large triangles. See p. 17 on the extra-large triangles. The principle here is the same. Plot on graph paper to maximize use of plywood. If you use entire triangles for windows, subtract from number of pieces of plywood you cut.



Fastening Skin to Frames

Plywood: Be sure to use *galvanized* fasteners—either nails or staples. A good staple gun—if staples have holding power—will save time. I used 6d hot dip galvanized nails, one every 6" or so and a bead of waterproof construction glue between strut and plywood.

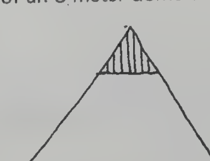
Where you have half pieces you should either run a strip of wood down the inside so that both halves can be nailed to it and seal outside seam

or you should fiberglass the inside of the seam, and waterproof the outside in the same way as you waterproof other joints. The halves are put together with 3/8" corrugated fasteners:

Nailing is done on a hard surface like concrete. If you fiberglass the inside (a 4" wide piece of fiberglass matt—cheaper than cloth—will do), do it *before* fastening plywood to frame.

This is an important step in plywood dome making. You must utilize halves, and the halves are usually the trouble spots.

With the large triangles of an 8 meter dome there is a 4" opening here:



This can either be patched with plywood or colored glass. I used amber glass; it made a beautiful hexagonal pattern around the hex hubs.

Leave the plywood off at least one large triangle, for entrance into dome. Seal edges by painting so if water leaks in it won't delaminate plywood.

Fastening Window Material to Frames

Whatever you use for windows—vinyl, mylar, fiberglass, glass, etc.—be sure to put a strip underneath it on strut so that when dome is assembled the window will be flush with the plywood. See p. 36

If there's a gap you'll have waterproofing problems.

Vinyl: I think of vinyl, even with ultra-violet resistants, as a temporary material. Mylar, fiberglass, or glass have much longer life. However, if you can only afford vinyl (or polyethylene), here is how to adhere it to frames:

Clear your working table of everything but the roll of vinyl. Roll vinyl out. Put triangle on, face down. Staple one edge, every 4" or so. Cut vinyl. Then staple second or third edges. Make fairly taut, but not too tight. When dome is put up, it will stretch tighter when struts are pulled together. In warm weather, vinyl will loosen; in cold weather it will tighten. Thus put it on the frames at a medium temperature. If you put it on in hot weather, and stretch too tightly it might rip apart when it gets cold.

PUTTING IT UP

Three is a good crew. More can be helpful, if you have good order and control.

One person should direct what goes where. For this purpose, *your model—color coded the same as the struts—is placed in the center for quick reference. See pp. 5-6.*

A scaffold with wheels and wheel-brakes is highly advisable here, with a 4' x 8' sheet of plywood to stand on. Don't leave tools lying on scaffold, as you'll kick them off and onto someone's head.

Start with bottom course. If you are drilling bolt holes as you go, drill one in the middle, one as close as you can get to each vertex. Clamp struts together as you go if it helps. Drill holes the same diameter as bolt as it makes a tight fit. Use washers, both sides. Pound bolts in with hammer.

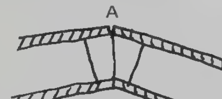
Two of you can tighten as you go, using ratchet wrenches. A pneumatic wrench would be ideal, like ones used for changing tires. We tightened bolts fairly tightly, but waited until the entire dome was up before the final tightening. This gives more flexibility as you go.

We had no need of braces. The dome held itself up as we went. With each course, the dome gets stronger.

You may have to custom fit the final triangle. After everything is in place, work from top down and give bolts a final tightening. This is a very exciting phase. You'll feel the dome creaking into tighter tension, becoming stronger, the membrane uniting.

Calculating for interior membrane: if dome diameter is 40', it is 20' from center of dome to A. To calculate for interior membrane, subtract distance between A&B from radius, and multiply times chord factor. If AB is 3", you multiply 19' 9" times chord factor.

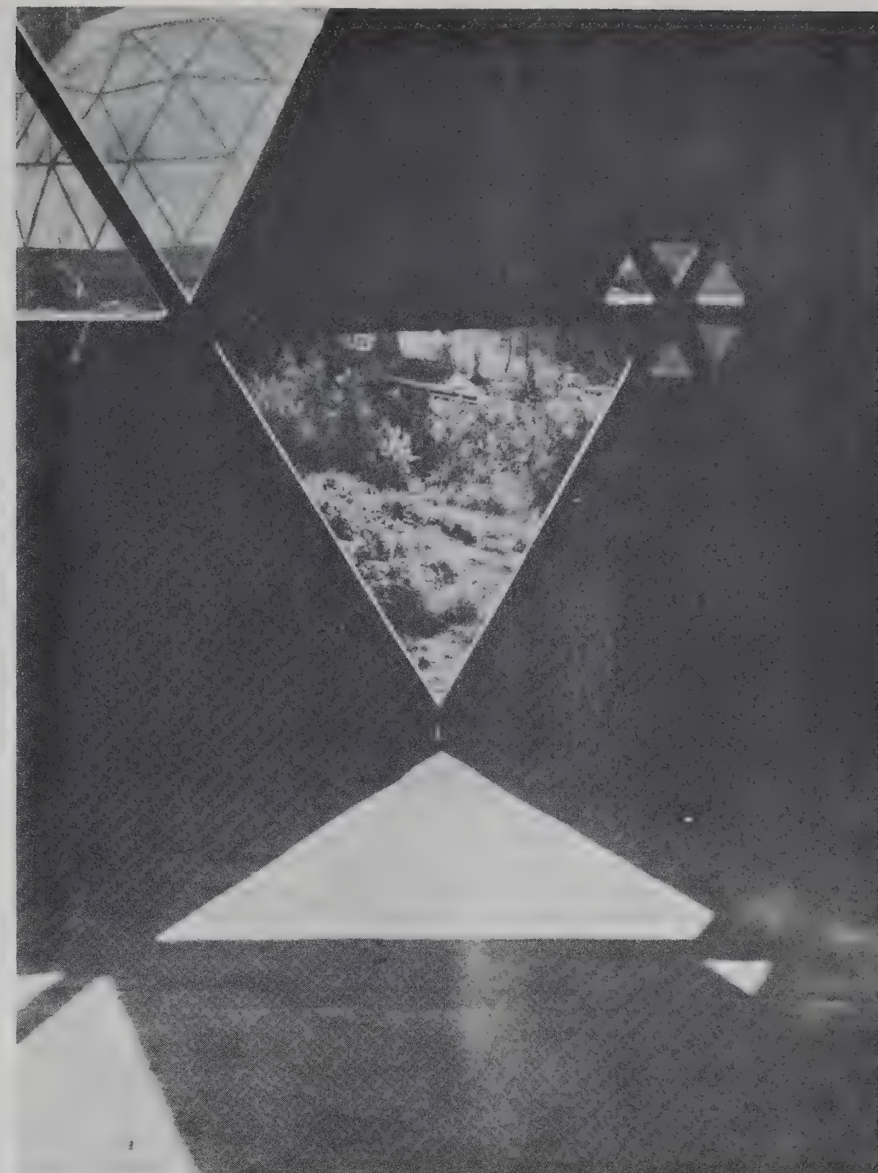
Note that you use the same measurements for strut length (unless there is a connector) and membrane length.



Put a mast on the top for climbing.

(See Table of Contents for **Doors**; **Windows**; **Vents**; **Sealing joints**—don't use fiberglass tape on this dome; it moves around a lot, and will crack tape.)

Tie a knot like this connecting drill cord to extension cord so it won't slip out when you pull on it.



ABOUT PLYWOOD DOMES:

We used plywood, and it may be necessary for you to do the same, because it is readily available, has a good strength/cost ratio, and can be cut out and assembled with hand tools.

However, there are several serious objections to the use of plywood:

1—Trees are critically needed for photosynthesis, and it is obvious that the lumber industry replants very little of the land that is logged.

2—Plywood is not a good dome membrane in that it does not seem to be good *skin* material. It moves around a great deal in expansion and contraction, and leakage is a problem unless you take the greatest care. If there is leakage, moisture sooner or later delaminates plywood. Moreover, a lot of paint, or fiberglass must be used to protect the vulnerable surface of plywood from the sun's rays. The entire skin of a dome is roof; and plastics, metals, ferrocement, etc. obviously are more suitable for shedding water.

In spite of these drawbacks, you may well find that plywood is all that will be available, or within your price or technological range.

Please don't follow these plans for Big Sur or Pacific Domes step-for-step. We were rushed, in both building and writing, and you should check all measurements and methods carefully for yourself. Design your dome, using our experience and description as a guide, and pick up where we left off.

The domes are easy to build, but you must exercise great care and take your time, as a dome won't tolerate funk. The pictures of our domes don't show our errors and mistakes. We have had leakage problems with domes not carefully sealed. Because the caulk was very difficult to apply evenly, the exterior seams are quite rough. We have not yet worked out completely satisfactory window details, or door and ventilation openings.

Our designs are far from perfected (perfection is a direction), but we've made a start. You may find that these plans can be adapted to use of other materials, such as wood framework with fiberglass, cardboard, vinyl, etc.

Let us know what happens—we need it for the next book.

Good luck!

Pacific Dome

We have built seven domes like this in about three months' time. Most of those on our building crew were 15-17 years old.

We used pipe-section hubs and stainless steel straps for the framework—a method first used by Fletcher Pence in the Virgin Islands about ten years ago. The skeleton framework is first strapped into place, a membrane is then attached, and joints are waterproofed.

We used 2 x 3's for the skeleton, 3/8" Duraply plywood for skin, clear ultra-violet resistant vinyl in geometric patterns for light, polyurethane caulk for sealing joints, and other ingredients listed below. The entire dome—struts and skin—will fit in a 3/4 ton pickup truck.

Much of what we have done with these domes was dictated by economy and local weather conditions (no snow, no strong winds, but a rush to beat oncoming rains, etc.) Your own particular site, climate and personal requirements will determine just how much of this will be useful to you. If your dome will be loaded with snow, you can't use flexible vinyl windows; if there are strong winds, as on the desert plains, you'll have to anchor the dome more securely, etc.

Use this as a guide, and design your own dome. There's room for improvement.

VITAL STATISTICS

Geometry: 3-frequency geodesic, 5/8 sphere, icosa-alternate breakdown, vertex zenith

Diameter: 24'

Weight: (not including floor) 2050 lbs

Volume: about 4400 cubic feet

Floor area: (not including lofts) 452 sq ft

Note: volume is a far better measure of living space, especially in a dome, as you'll not be confined to the floor area.

DOME INGREDIENTS

- 12 pieces 4' x 7' plywood for small triangles
- 24 pieces 4' x 8' plywood for large triangles
- 6 pieces 4' x 9' plywood for extra-large triangles

} subtract for windows

- about 750 lineal feet 2 x 3's for struts (of 8' and 10' lengths). Figure the proper number of each to order.
- 61 hubs, cut from sections of pipe
- about 500' stainless steel strap, about 400 stainless steel buckles
- about 20 lbs 4d or 6d hot dip galvanized nails
- quantity of window material up to you
- 12 tubes of caulk
- 2 1/2 gallons primer, 2 1/2 gallons finish coat paint
- misc. materials for vent, door, etc.
- floor materials not included

Type of materials we used

Struts: kiln dried 2" x 3" douglas fir without large knots. You don't need clear lumber, but there should not be knots that will be structurally weak. Kiln dried wood is about twice the cost of green wood. We used it because it will not shrink once in place. However, reasonably dry lumber will do. The difficulty here is shrinkage causing distortion causing leaks.

Plywood: U. S. Plywood "Duraply" is the only plywood I know of that has a lifetime (of the building) guarantee to not de-laminate, etc. It is impregnated with resin and surfaced with a waterproof paper designed for paint application and waterproofing. Any other plywood will not hold up to direct sun exposure for any length of time, so this type should be used unless you are going to cover the exterior with something other than paint—such as sprayed-on fiberglass, or shingles.

Hubs: we got some 10' lengths of 3 1/2" (outside diameter) 1/2" wall aluminum pipe from a surplus yard, cut it on a band saw into 2 1/4" lengths, filed down the edges so pipe wouldn't cut into strap or hands.

Straps and Strapping Device: If you can get the strapping tools, and have access to a drill press for drilling struts, this is a simple and quick way to frame. The 1/2" straps and buckles are stainless steel which does not corrode. If you get a strapper, there will be instructions on strapping technique with it.

Nails: use hot dip galvanized nails. Electro-galvanized nails rust badly.

BUILDER'S INSTRUCTIONS

Cutting Struts: You need either a radial arm saw or much patience and care. A radial arm saw allows you to cut all pieces exactly the same length.

General instructions on cutting

1—First cut boards in half for easier handling.

2—Check carefully the first one you cut at a new setting; the length with a tape measure, the angle with a protractor. If it is perfect, then cut the rest.

3—About every 10 cuts, check stop-table mark. The stop tends to creep along the table as the wood bumps it.

4—Sweep sawdust off table frequently. It tends to collect along fence and against stop.

5—Make some extras of each length just in case.

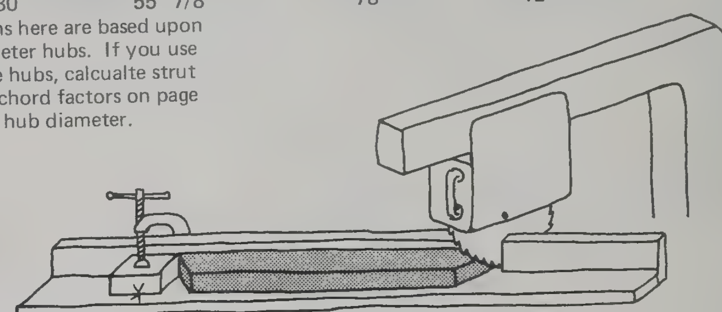
6—Saw smoothly and slowly.

7—Wear goggles.

Table of struts: make a large, clear copy of this and post by the saw.

Strut	Number to cut	Length, using 3½" diameter hubs*	Axial Angle both ends	Angle at which you set radial saw
A	30	46 11/16"	80°	10°
B	55	54 5/8"	78°	12° *Check shop yoga*
C	80	55 7/8"	78°	12°

*Strut lengths here are based upon 3 1/2" diameter hubs. If you use different size hubs, calcualte strut length from chord factors on page and subtract hub diameter.



Radial saw

Angle: use an adjustable protractor to double check the saw's gauge. Hold it against fence, pull blade out and check to see that blade parallels protractor.

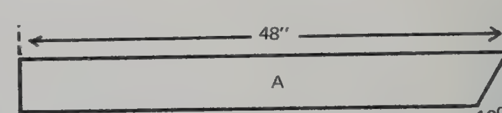
Length: tape measures are made to hook over a piece of wood. For greater accuracy, use the 1" line on the tape measure and line it up with inside of saw blade. Add 1" to total measurement when setting stop. V-mark stop and table and check the stop for slipping periodically while sawing.

Make sure table and fence are made of clear straight wood. Close one eye and sight down the fence.

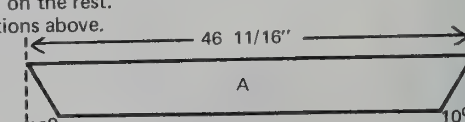
Shop Yoga

Our radial arm saw's gauge was such that a right angle cut across a strut reads 0° on the gauge. Therefore, the settings for the cuts were 10° and 12°. If your saw's gauge reads 90° for a right angle cut, angle you cut will be complement of 90°. That is, 80° instead of 10°, etc.

CUTTING A's



First cut: (in half)
Set stop at 48"
Set angle at 10°
Cut first one and check for length and angle. Make adjustments if necessary and go ahead on the rest.
Follow general instructions above.
Stack neatly.



Second cut: (to length)
Set stop at 46 11/16"
Leave angle at 10°
Cut first one. Check very carefully for length and angle.
Continue as above.

Color code: Stack them in a neat pile; spray-paint tips of each end red.

CUTTING B's

First cut: (in half)
Set stop at 60"
Set angle at 12°
Cut first one and check for length and angle. If o.k., cut the rest.
Stack neatly.

Second cut: (to length)
Set stop at 54 5/8"
Leave angle at 12°
Cut the first one. Check carefully for length. If o.k., cut the rest.

Color code: Spray-paint tips of both ends blue.

CUTTING C's

First cut: (in half)
Set stop at 60"
Leave angle at 12°
Cut first one and check for length. If o.k., cut the rest.
Stack neatly.

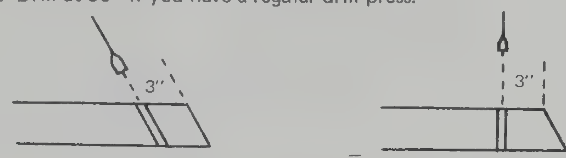
Second cut: (to length)
Set stop at 55 7/8"
Leave angle at 12°
Cut first one. Check length carefully. If o.k., cut the rest.

Color code: Spray-paint tips of both ends yellow.

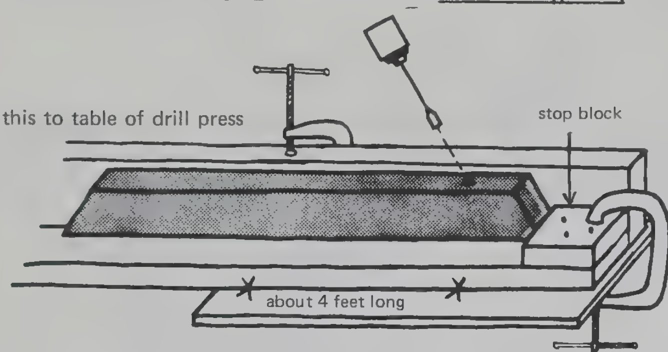
PACIFIC DOME *continued*

Drilling Struts

It is essential that the hole be drilled very accurately, so use a drill press. The hole must be centered, and if you have a radial drill press, drilled at the same angle as the strut end. Drill at 90° if you have a regular drill press.



Jig:
Clamp this to table of drill press



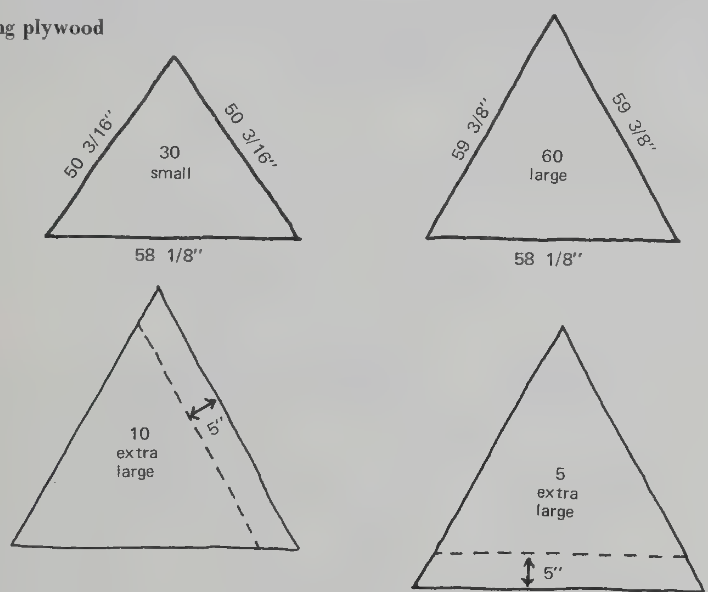
Using a paddle type blade, drill all the way through strut. Disregard minor splintering where bit breaks through.

Have a big enough block under bit so you don't drill holes in drill table.

Sweep shavings out of jig after each hole; otherwise the next strut will be out of position.

V-mark jig & table and check for slipping periodically while drilling.

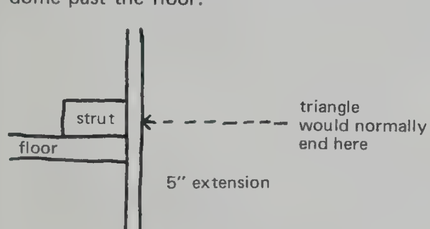
Cutting plywood



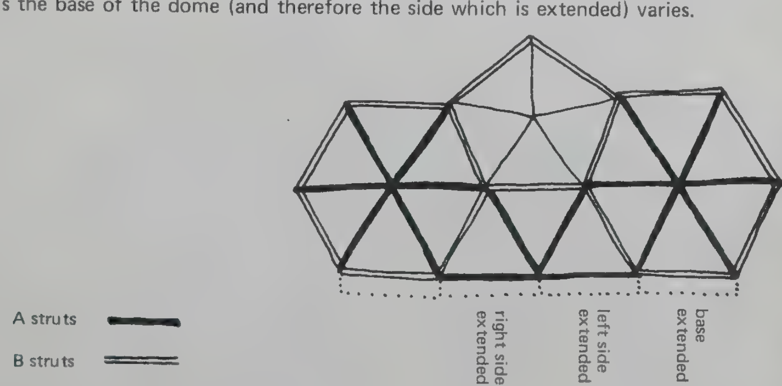
The number of triangles shown above are for covering the *entire* dome with plywood. Adjust accordingly (subtract) for windows, doors.

Plot on graph paper how best to utilize plywood for the size dome you are making before ordering. Find most economical way to get triangles out of rectangles. For our domes we found 4' x 8' sheets good for the large triangles, 4' x 7' sheets good for small triangles, 4' x 9' for extra large triangles. Draw the plywood sheet on graph paper, cut out small triangles, move them around to find the most economical arrangement.

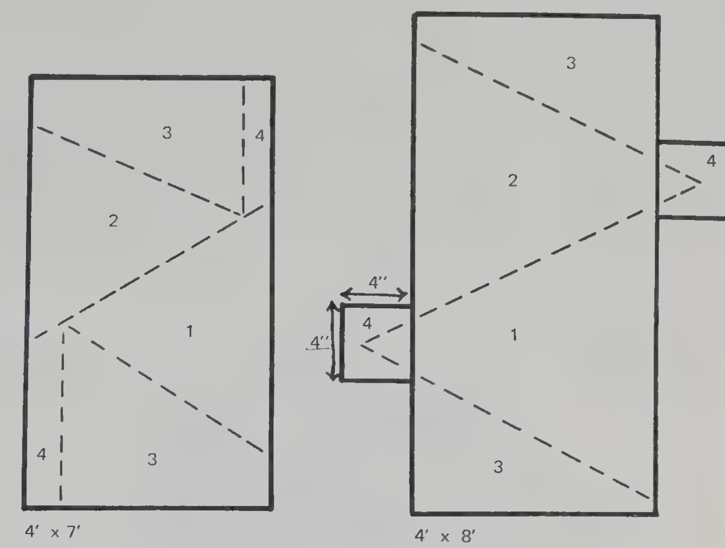
The 15 extra large triangles are for the base course—so that water will run off the dome past the floor.



There are three different kinds of extra large triangles because their orientation towards the base of the dome (and therefore the side which is extended) varies.

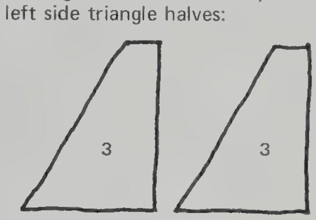


Plywood triangles layout: with graph paper we determined that this was the best utilization of plywood:

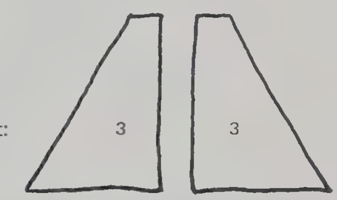


Note that you cut two whole triangles and two halves from each sheet. The halves are patched so that you get three full triangles per sheet.

If you are using "Duraply" or any other type of good-one-face plywood, you will have to flip over every other piece you cut. That is, you will cut one good side up, the next good side down. If you cut all pieces good side up, you would end up with all left side triangle halves:



Therefore, by flipping every other sheet you get:



PACIFIC DOME *continued*

Cutting jigs

Setting up a jig makes sure you cut all pieces of plywood exactly alike. You can't be accurate enough trying to follow a pencil line with a skilsaw. The first type of jig here was designed by Bill Woods, and is perhaps best for making one or two domes. The second type of jig, more complicated to make, was designed by Wayne Cartwright and was used for our seven plywood domes. It is quicker to use in mass production.

Following are descriptions of both types of jigs—briefly of the first, in more detail (including usage) of the second. If you use the first, adapt the instructions according to what you are doing.

Before constructing either jig, study fig. 1. "d" indicates the distance from edge of template and saw guard to *inside* of blade, which must be considered in determining the placement of the aluminum strip or the size of the template triangle. Also set the blade depth so it won't cut through the jig.

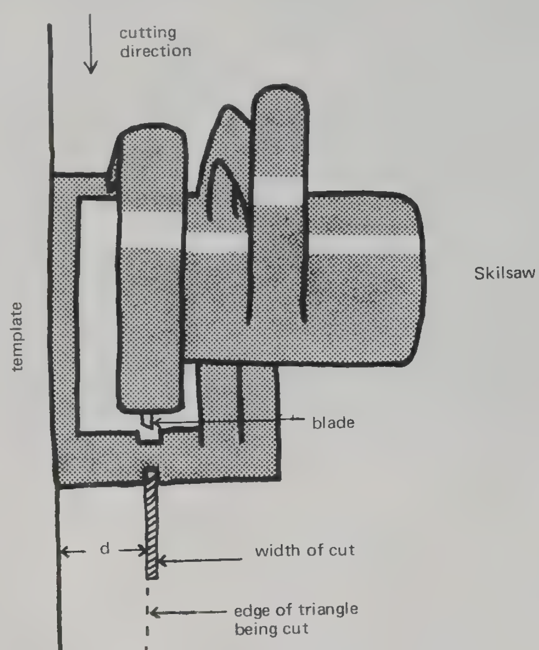


Fig. 1

Bill's jig:

This jig works best on a concrete floor. The stops hold the plywood snug for cutting. Make them of the same thickness as the plywood you are cutting and nail them on.

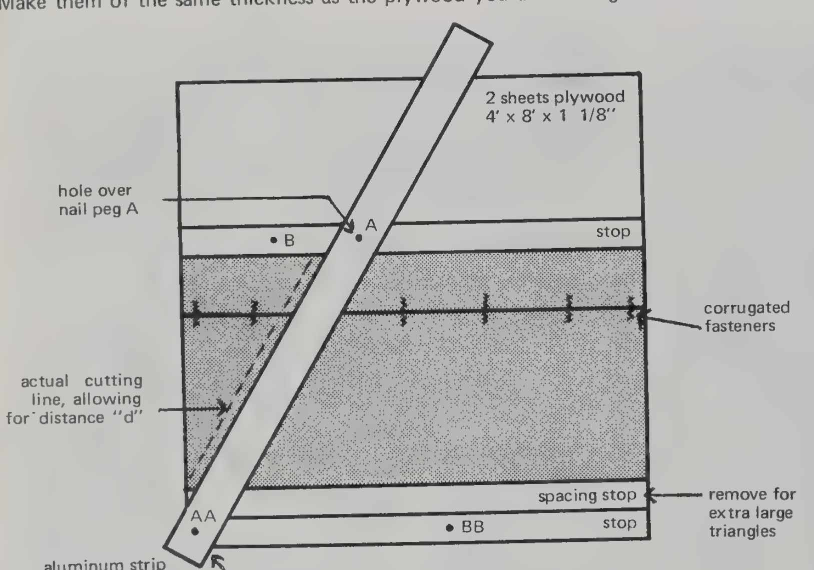


Fig. 2

The aluminum strip has holes in it so it can be held in place by pegs (16d nails with heads cut off) which are pounded into the stops. Carefully draw a master triangle on the jig and then position the aluminum and nails, not forgetting distance "d".

After cutting one edge, aluminum on nails A and AA (fig. 2), flip the metal onto nails B and BB and cut the other side of the triangle. (Fig. 3)

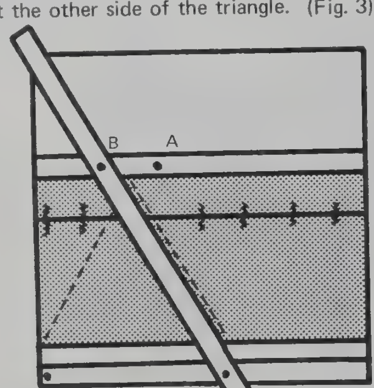
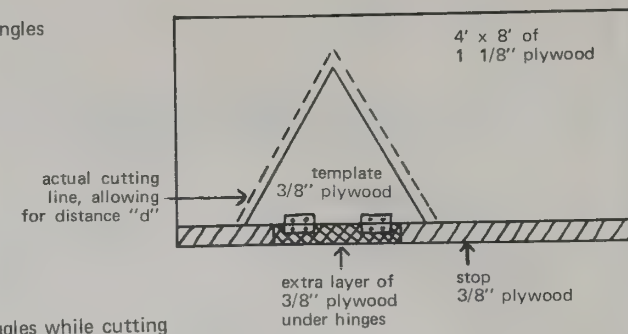


Fig. 3

Wear ear guards and goggles while cutting.

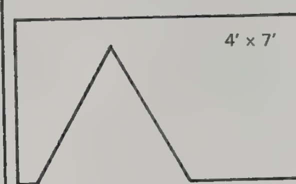
Wayne's jigs: Small triangles



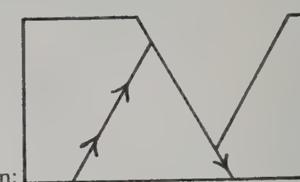
wear ear guards and goggles while cutting

Stops are the same thickness as the plywood you are cutting and are nailed on. There must be an extra thickness under the hinges so that the template can lie on top of the sheet you are cutting. Screw the hinges to the stop and base beneath and bolt them to the template.

Lay in a sheet of plywood to be cut, making sure it's tight against the stop and the ends are lined up. Cut out the first triangle, which leaves a piece like this:



Turn it around and cut again:



Remember to flip every other sheet over. Cut the piece 4 section off the halves (fig. 4), then paint primer on the edges where they will fit together to discourage de-laminating. Fasten the halves together with corrugated fasteners the same size as the plywood (3/8"). Longer ones will come through the plywood and make leak problems. Hammer them in on a firm surface (concrete floor is best) with good side of plywood down. Then put the triangles back in the jig and cut to size.

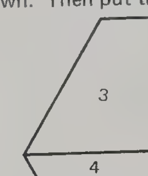
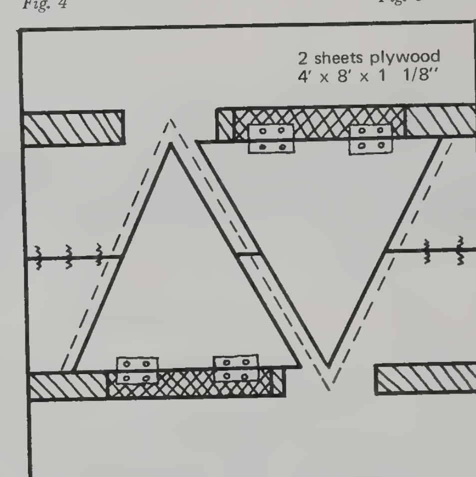


Fig. 4

Fig. 5

large triangles



Wear ear guards and goggles while cutting.

Breaks in stops allow for tips needed on large triangles.

Lay a piece of plywood in the jig with tips attached (see large *plywood triangles layout*). Make the tips out of the scrap (section 4) from the small triangles, and prime the edges before you attach them. Lay one template down on plywood, make two cuts, being sure saw guard is against template. Fold template back, lay other template down and cut. Take pieces out and stack. Repeat operation, making sure that you cut half of the sheets face down. Prime the inside edges of triangle halves and tops and fasten them together. Then cut to size in the jig.

extra large triangles

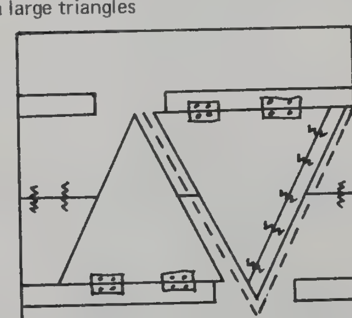


Fig. 6

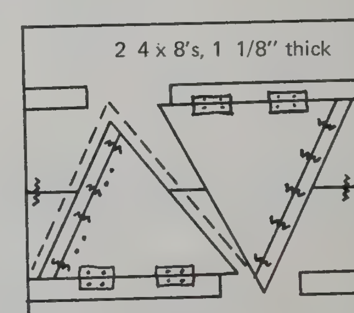


Fig. 7

To cut the extra large triangles that have extensions on the side, nail a 5" wide strip along one edge of one of the templates. (Fig. 6) Using this template cut 5 triangles face up and 5 face down. As you cut, mark the extended edge as a right edge or a left edge.

To cut the extra large triangles with extended bases, unbolt the other template, turn it a third of a turn and bolt one of the side edges back on to the hinges. Then fasten a 5" wide strip along that base edge and cut and mark five triangles. (Fig. 7)

The tips for the extra large triangles must be made from pieces bigger than the 4" x 4" pieces. Don't forget to prime.

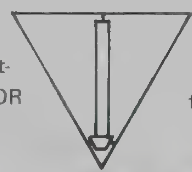
PACIFIC DOME *continued*

Treating Patched Pieces and Plywood Edges

You should also prime the edges of plywood triangles before nailing onto dome. This will prevent moisture from delaminating plywood.

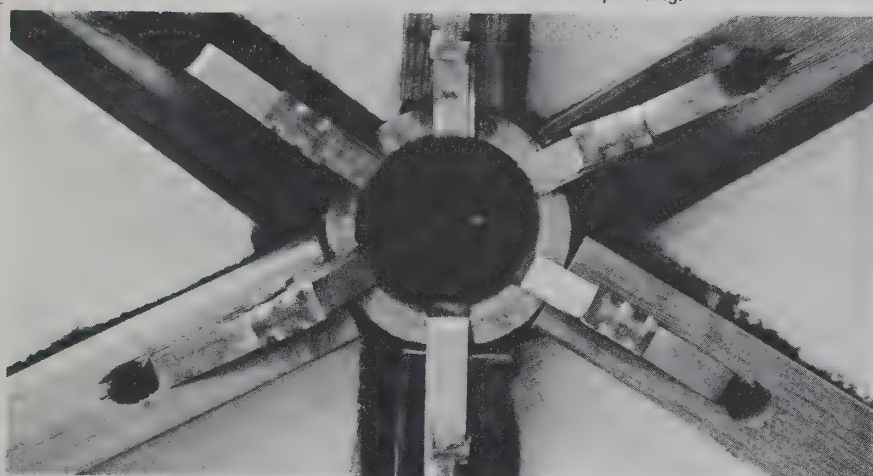
The patched pieces are the worst potential trouble spots. When the dome expands and contracts, they tend to open, and consequently leak. You can do two things:

insert wood strips to nail edges to. Leave enough space for struts. Tape outside, after painting.



OR

fiberglass tape inside, use either fiberglass or other type tape outside, after painting.



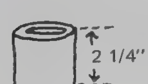
Making Hubs

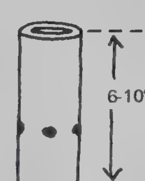
Hubs made from metal pipe will be better cut on a power hacksaw. The burr should be filed off to prevent the strap from being cut by the sharp edge. Plastic hubs have been used, but they will not take high loads such as suspended decks, snow, or high winds, particularly if there are large window areas which prevent the plywood skin from acting as a structural member in that area.

We used 3 1/2" outside diameter pipe.

If you use different sized pipe for hubs, adjust strut size accordingly.

Cut in approximately 2 1/4" sections.





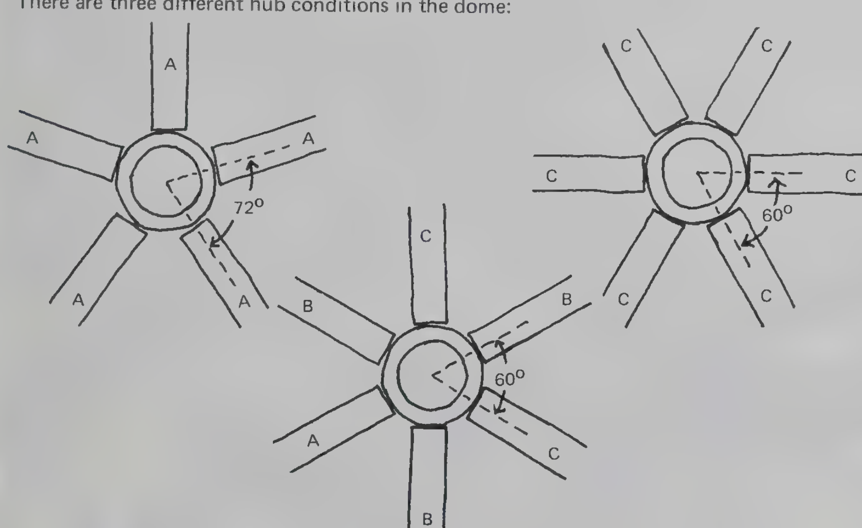
There are 60 regular hubs in this dome, and one mast hub.

The mast hub goes at the top, in center of pentagon, and is used for throwing your climbing rope over. *See page 27 on climbing.*

Drill holes for straps.

One thing that should be done, and that we didn't do, is to mark the hubs for proper positioning of the struts. Otherwise you're just guessing when strapping on struts, and you'll have trouble getting plywood evenly spaced around hubs.

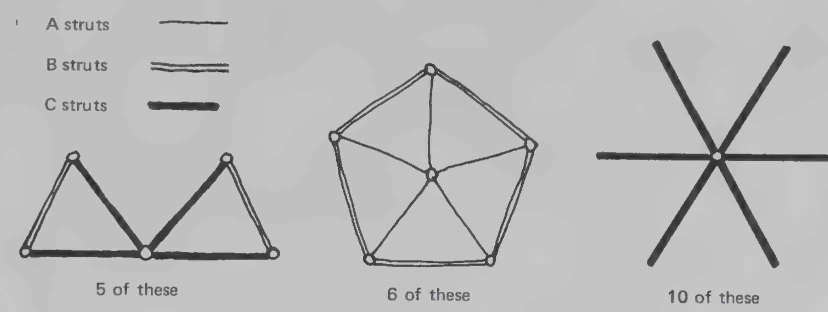
There are three different hub conditions in the dome:



To make a jig you might get three sections of pipe that will fit inside the hubs (outside diameter of jig pipe is same as inside diameter of hub pipe). Using protractor, mark jig pipe at appropriate intervals; notch with hacksaw, and use it to scribe marks on hubs.

Prefabrication

Using color-coded model, pre-assemble struts into units like this:



Strapping: Here the cost of the strapper and crimper (about $70) was justified for us as we built several domes. Here's how to use them:

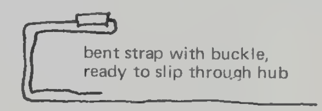
Learn to use the strapper with instructions that come with it.

Assemble prefab components on a big table with a few people helping you hold struts.

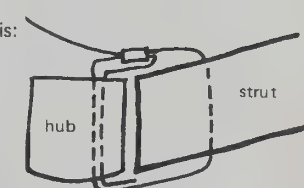
Once you determine the proper length strap you can cut a number of them.

We doubled strap where it grips the hub so the metal wouldn't cut into the strap.

While one person is strapping, another can cut straps, put on buckles, and bend.



This is then slipped through strut and hub like this:



Strapper is engaged:

Line up strut with mark on hub.
Crank until it is tight. Crimp buckle.
Break off end of strap.

PUTTING IT UP

Women bake bread and prepare food for when it's completed. You'll want to spend some time sitting inside the skeleton. Pick a nice day. Invite a lot of friends.

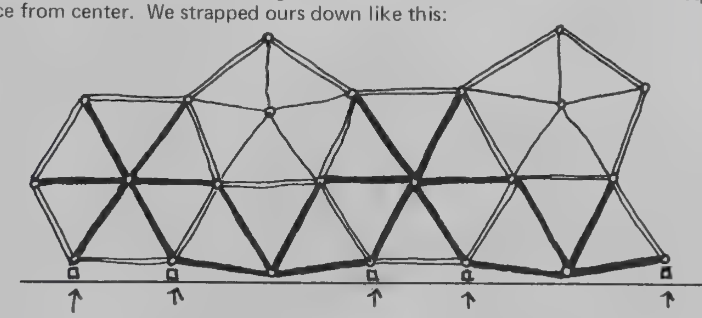
A scaffold is essential. Rent one, with wheels and wheel steadiers, that will go up to about 7'.

Set model in center. Start at bottom course. It is best to have one person who just designates what goes where. Work around, and up. *Temporarily tie it down if there's a wind.* It will start holding itself up during the second course.

Strap as you go. One man on strapper, another working the crimper.

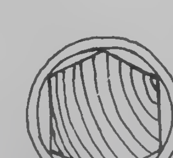
When it is finished, climb on it, hang upside down, swing around, then rest and eat.

Next, attach to floor. Take an average from center of floor. Place each strut an equal distance from center. We strapped ours down like this:



Drill holes in floor and strap each hub to floor. Strap it securely, so dome won't blow off. If you don't strap, work out a means of bolting down.

If you use plastic hubs there should be blocks inside base course hubs so weight of dome is not resting on pieces of plastic.



Cut floor off to fit dome.

PACIFIC DOME *continued*

SKINNING DOME

You should wait a while, sleeping under framework, seeing where the morning sun rises and planning carefully where to admit light. This will vary according to season. When this is decided you can start with the plywood skinning. Make sure struts are equally spaced around hubs. You can do this as you go, lining up struts with marks on hubs. Be careful, as errors will accumulate.

If you caulk, staple strips of polyethylene to struts with rustproof staples. Best to start from top, as it leaves room underneath to stand on struts.

Nail triangles on with hot dip galvanized nails. Electro-galvanized nails will rust. One nail about every 4" or 6". Or rent a pneumatic staple gun that shoots rustproof staples and *be careful* of people below.

Have a helper handing triangles up to you.

The struts must be accurately positioned around hubs.

Nailing should be done very carefully. Don't leave any hammer marks on surface, as they will complicate the sealing of joints. Go slowly here. Everyone wants to nail on triangles. Two or three nailers is about right, but check each one out to make sure he is hammering well, and placing triangles carefully. We had a careless nailer on one dome and later had to custom fit some triangles.

At bottom course, where large triangles overlap, first nail on one, then a few nails to hold the overlapping one, and saw down the middle.

Calculating for interior membrane: see note on this in Big Sur dome. You will use a different radius times the chord factor for calculating interior paneling.

(See table of contents for next steps: **sealing joints; doors & windows; interiors.**)

Tube Frame Dome

Tube framed domes have many advantages over wood for certain uses. They use mineral materials instead of killing trees, and when obsoleted their scrap can be largely recycled. Tube frames are well suited to flexible non-load-bearing skins and are the simplest way to make a "sky break" with no skin at all. They can be skinned in several ways: a fabric tent suspended inside the frame by rubber bands; a fabric tent applied to the outside of the frame and resined; fiberglass or metal sheets; Plexiglas; or even plywood. Transparent or translucent panels can be made from vinyl and inflated. The frame can be covered with a net or mesh and foamed or ferrocemented. Many other skins could be tried using the basic principles outlined below.

VITAL STATISTICS (for Bubble Dome)

Geometry: 3-frequency geodesic, 5/8 sphere, icosa-alternate breakdown, vertex zenith

Diameter: 20'

Weight (not including floor): 600 lbs

Volume: about 2600 cu ft

Floor area: 314 sq ft

THE FRAME

Any suitably strong tubing can be used, but the cheapest and easiest to get is "EMT" electrical conduit. It is easy to work with and is plated, so painting isn't necessary. 1/2" is not suitable for any domes that will be subjected to heavy weather conditions, but it is useful for indoor structures and small (up to 14 feet diameter) domes. 1/2" conduit will bend if climbed on. 3/4" is best for most uses. It wholesales for about 9¢/ft. Using the chord factors, you can use 3/4" conduit in triangles whose sides are up to 4 1/2 feet long. 4 feet is maximum where there will be snow loads. This will result in about a 24 foot maximum diameter in 3-frequency. For larger domes you will need bigger tubes or a higher frequency. Bigger tubes are hard to squash! Think first. (See "What Size?" p. 49)

Cutting

The tubes should be cut according to the chord factors *plus* 1 1/2". The chord factor gives the "center-of-hole to center-of-hole" length, and there must be about 3/4" beyond the holes. Conduit comes in ten foot lengths. You get two struts from each length for making domes up to about 24 feet diameter. If you are making a smaller dome, try to size the dome to minimize waste. Perhaps you can get three struts from a length if you combine two A and a B or something like that. Think before cutting. Make the cuts with a hacksaw or a tube cutter. We find that conduit cutting blades for a table saw are actually slower than a hand hacksaw. Use a 16 or 18 tooth hacksaw blade. Hold the tube in a vise with a stop on the bench positioned so that a cut made right against the jaw of the vise will be the correct length. Keep the tubes in separate piles. Garbage cans make handy holders.

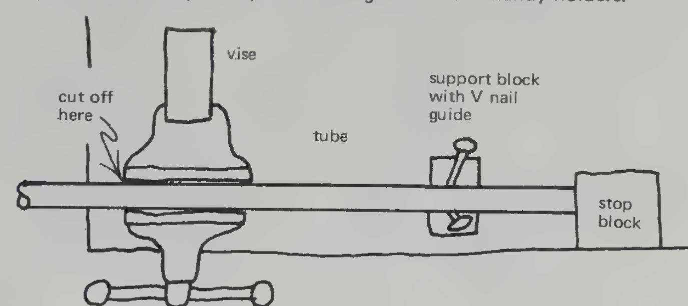


Fig. 1

Squashing

Flatten the tube tips 2 1/4" from the ends, by squeezing them in a vise. A *big* vise. Small "home workshop" vises will break. (BABCO makes big cheap vises). Squeeze the tubes horizontally in the vise. If the jaws are not big enough, stick on small pieces of angle iron (1 1/2" wide) with putty to enlarge the squeezing area of the jaws. (Fig. 2A) Make a mark on the jaws 2 1/4" in from the edge as a guide for depth of squeeze. (Fig. 2B) Insert the tube, holding it perfectly horizontal and centered in the jaws vertically so that all of the tube will get squashed. Oil the vise screw threads to make the turning easier. It will probably be necessary to use a "persuader" pipe on the vise handle about 2 feet long, but be careful not to over-strain the vise. EMT tube has a weld running the entire length of it. If the tube is positioned in the vise so that this weld comes at the very edge of the squashed tube, it will split. To prevent this, the tube should be positioned in the vise with the weld at 2 o'clock. (Fig 2A) Splits along the edge of the flattened tube are rejects. Splits in the middle of the flat are undesirable but usable. To squash the opposite end, eyeball the flat you have just made and insert the other end in the vise as nearly in the same plane as you can. This end will automatically have the weld positioned correctly, so you don't have to worry about it. The tubes should be squashed as flat as you can manage with your vise, but a small amount of "lips" is acceptable. (Fig. 3) You can flatten these with a hammer later. If the dome is to be skinned with plastic film or fabric that touches the frame, file or grind off the sharp corners of the tips at this time. These tips will rust, so they should be painted silver with rust-preventing paint. The vise-squeezing bit is tiresome. Try and wangle someone into doing them on a press in a machine shop. Hammering tips flat without a vise results in poor fit and a generally crappy appearance.

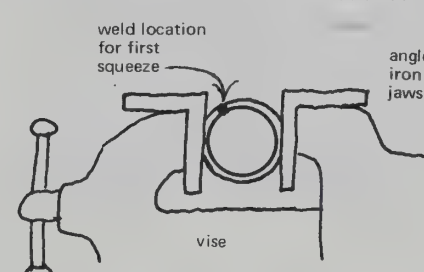


Fig. 2A

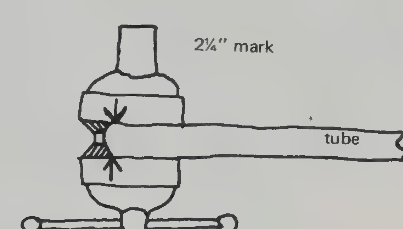


Fig. 2B

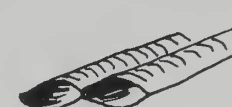


Fig. 3

Drilling

To drill the first hole in each strut, cut a Vee groove in a 2 x 4 six inches longer than the C strut, and clamp it to the drill press table with C-clamps. (Fig. 4A) Nail a stop block across the groove so that the drill hits dead center on the flattened tube tip and the edge of the hole nearest to the tip is about 3/4" from the tip. (Fig. 4B) For 3/4" conduit a 3/8" bolt should be used. To facilitate assembly and absorb errors, the hole you drill should be 7/16 or 15/32".

To drill the second hole in each strut, measure *exactly* the correct hole-to-hole distance (that the chord factor has shown to be correct) along the 2 x 4 and drill a 3/8" hole there. There will be a hole for A, B and C. In the A hole screw in a 7/16" bolt that has had its head cut off with a hacksaw (Use a Vise-grip or pipe wrench). File the cut-off stump to a sort of point so that the first hole already drilled in the tips of the struts can easily fit over it. Again clamp the 2 x 4 to the table so that when the tube has its first hole impaled over the cut-off bolt pin at the

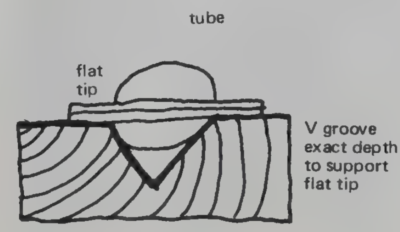


Fig. 4A

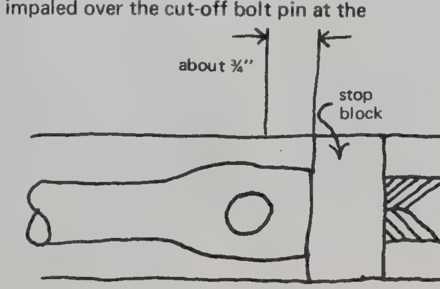


Fig. 4B

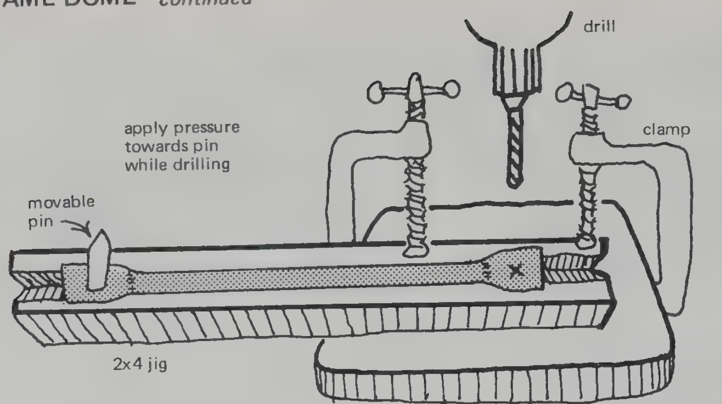


Fig. 5

other end of the 2 x 4, the second tip will be under the drill at precisely the correct place. (Fig. 5) Start the drill and lightly touch it to the tube. Stop the drill and measure from the *center* of the first hole over the bolt to the drill scratch to check if it is the correct hole-to-hole distance. If it's o.k., you can quickly drill all the second holes accurately in the A struts. Repeat for the B and C struts (moving the pin), checking each time for accuracy before drilling the whole batch. Mark the table and the 2 x 4 so you can check if the jig is moving as you work (which is disaster). Hold the strut with pressure against the pin to take up any slack. This eliminates most error. Careless drilling will result in maddening misaligned holes during assembly!

Bending Tips

The tips can now be bent to approximately the angle that they will have in the finished dome frame. Do this in the vise by inserting the flattened tip in the vise and bending the tube to a stop block nailed to the table. Allow for "springback" by bending a bit further than seems right. A few tries will show the proper place. For a 3-frequency dome, bend the A struts to 10 1/2° and the B and C struts to 12°. Accuracy in this bend is not important. (Fig. 6) Accuracy in drilling the holes is *very* important unless you like lumpy domes assembled by beating them with a sledgehammer. If flattened tips have split across the hole, they should be bent *towards the split side* so split will be *inside* the dome.

Bolts

The bolts should be long enough to go through six flattened tips (remember that they probably vary in flatness. Assume they are all as thick as the worst one you can find) and two washers (one on each side of the stack), plus enough to easily get the nut onto. It is well to have them an inch longer than that, or even longer—which is handy for attaching things to the dome later. The bolt heads will be inside the dome and the nuts outside. We use ringbolts (with the ring inside) so that we can easily hang things from the inside of the dome. Be sure to get them with enough thread near the neck to tighten the stack of tips properly. Tips should be stacked in an order that makes any given triangle as level as possible. (Fig. 7) This will vary with the type of skin that will be used, but in any case, make each stack of a given type (hex, pent, irregular hex) the *same way*. This will make re-stacking easier if that should prove necessary, and will make the dome symmetric. Different types of skin will require different stacking. Think it out, and make a *test section* before charging.

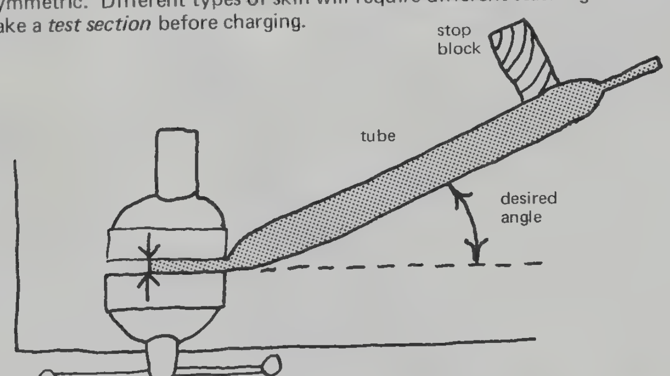


Fig. 6

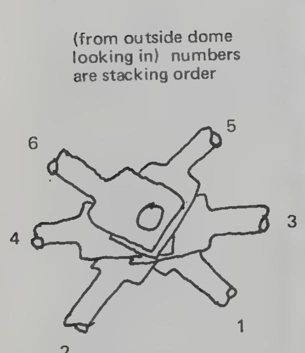


Fig. 7

Assembly

Assemble the frame starting at the bottom or top (and lift it as you go), as you prefer. For larger domes start at the bottom. Bolt the bottom course tightly, but only stick a bolt through the next layer so that it will be easy to add to. If you have drilled accurately the dome will go together very quickly using two stepladders or a scaffold. Up to about 30 feet, no supports will be needed. *Remember that the removal of any strut* seriously *weakens the dome!* Removed struts, as for doors, etc., MUST be compensated for with extra bracing that maintains the angles!

Before adding any skin of any description, it is ABSOLUTELY NECESSARY to fasten the dome securely to the ground, or it will take off and fly remarkably well.

A lightning ground rod is also ABSOLUTELY NECESSARY! Connect to any hub bolt.

A three-frequency dome doesn't sit flat on the ground, but rather sits on five points. You can either block up the other ten points or lower the dome on the floor so that the five low points are below platform level. In any case, it will be necessary to support ALL the points if the dome is to be really strong. Remember that wind *lift* is the largest load your dome will take, other than heavy snow.

SKINS

Suspended Skin

The tube dome can be skinned with fabric by sewing together triangular panels that are somewhat smaller than the chords of the tubes but are in the same ratios. If the cloth is wide enough, several panels can be made together rather than making all the triangles. The pieces should be sewn together using a double needle industrial machine and Dacron thread made specifically for tent making. Materials such as muslin and canvas can be used. For permanence, Hypalon or Acrilan are best but expensive. The seams can be "fin seamed" if they're hemmed first. This is a drag, and the best seam is the "welt seam" unless a special tentmaking machine is available. (Fig. 8A) A home sewing machine will not work well unless the dome is small or the fabric very light. A parachute will fit over a geodesic frame, but will be difficult to waterproof and will not fit perfectly. OK for summer shade. These skins can be attached to the ringbolts with innertube bands cut with tin snips, from truck tubes. Car tubes are too weak. Attach with #3 grommets at vertices and short knotted ropes through the rubber bands. (Fig. 8B)

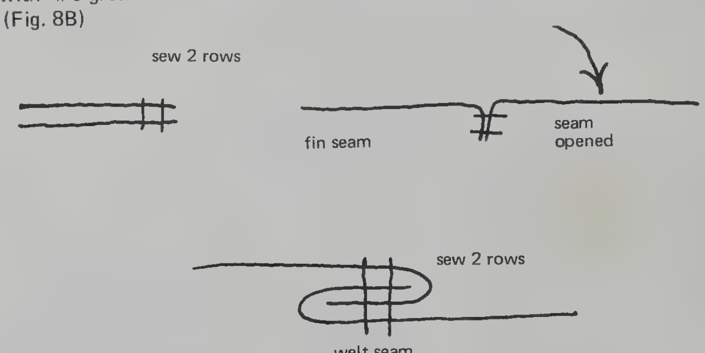


Fig. 8A

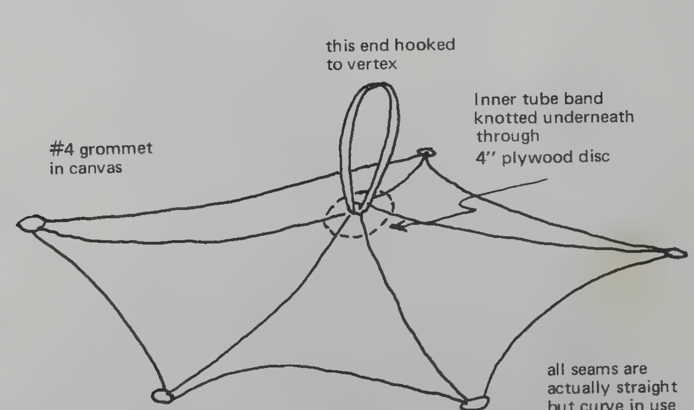


Fig. 8B

External skin

An external skin can be made from triangles the same size as the *outside* of the tube frame as measured in several sample places. Be sure and allow for shrinkage! The skin can be sewn to the frame here and there. These skins will leak unless resined. Apply a heavy coat of flexible resin or foam. Resin can be applied with a weighted paint roller with a hinge in the stick to get you over the hump. This will result in a translucent watertight dome. It will "boom" if thumped in a way that might drive you crazy if wind conditions were wrong.

Thin Sheet Stock Skin

The frame can be skinned with fiberglass sheets such as "Filon". This method will also apply to sheet metal. Cut the sheets into triangles about 3/8" larger than the tube frames. (With a 3/4" tube frame, cut the sheets as large as the outside edge of the tubes in all cases.) Drill through the sheet triangles while they are in position, and rivet them on with POP rivets, overlapping the triangular sheets at the edges and particularly at the hub bolts in a shingled manner so as to shed water. Putty around bolts with DUM-DUM (see below). This means that you start at the bottom and apply the "point up" triangles first, then the "point down" triangles of each course. Where the struts are vertical it doesn't matter which edge is over which. If the panels have been cut the right size, the overlap along each edge will be about 3/4" and in most cases this will be enough waterproofing. (Fig. 9) If a test panel shows that there will be a gap that will admit wind excessively, a caulk could be applied between the panels before riveting. Use a caulk that is flexible and sun resistant and that will not attack the panel material. If the panels buzz against the tube frame, get a box of "strip-caulk" at an auto supply store (also referred to as Dum-Dum) and roll it into little balls and stick it to the tube frame between each rivet. This will dampen vibrations. It could also be rolled out into long thin snakes and used as caulk between the panels. (It's cheap.) Domes skinned this way can be insulated by applying one inch or thicker styrofoam panels with mastic to the inside surface, for metal domes, or clips for translucent Filon. Use fire retardant foam. This will still let a bit of light through fiberglass panels, but it won't be really very bright. It's about the only practical way to insulate such domes, because you won't have to make another skin for the interior, and this ends up costing less in the long run.

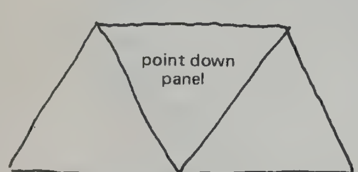


Fig. 9

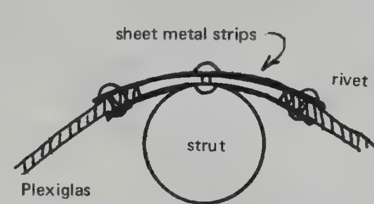


Fig. 10

Plexiglas skin

Domes can be skinned with transparent Plexiglas. This cannot be insulated, remember, and still be transparent. It is very expensive, and it requires an extra strip of sheet metal to rivet it to, as you can't overlap Plexiglas like you can fiberglass or metal. The strips are about 1 1/2" wide 20 gauge and are POP-riveted to the tubes first and bent into a shallow V about 14° lengthwise. These strips must be "shingled" at the hubs, and puttied. Then rivet the Plexiglas to the strips. Make the holes in the Plexiglas oversized (e.g., 1/4" for a 1/8" rivet). This will allow for the huge expansion and contraction of Plexiglas which would otherwise break the panels. A second strip, also shingled at the hubs, goes over each joint with caulk or Dum-Dum on both strip surfaces. (Fig. 10)

Plywood skins

Plywood panels can be attached with "one hole clips" and 1/4" bolts. Cut the plywoods with their edges exactly according to the chord factors of the tubes. Paint the plywood panels and let them dry thoroughly. Paint must be free of rough dirt. Then tape the joints with 2" wide weatherproof electrical tape (black lasts longest), shingling it at the hubs and dum-dumming around the bolts. You will have to carefully think out how you stack the tubes if you are using plywood, as it can take just so much bending. (Fig. 11) Try to avoid large "stair-steps" from panel to panel that would make taping difficult.

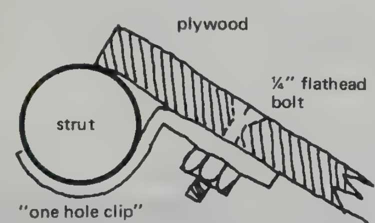


Fig. 11

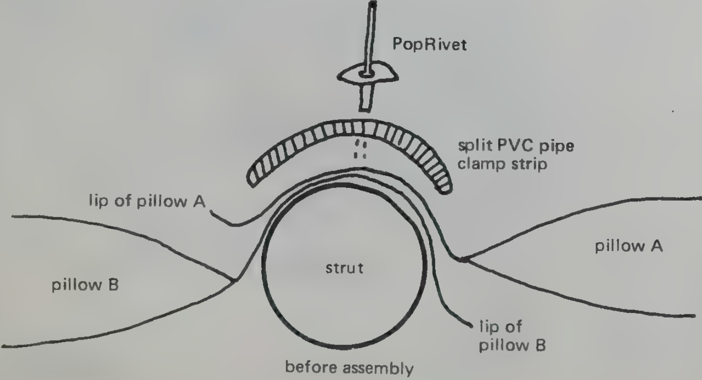
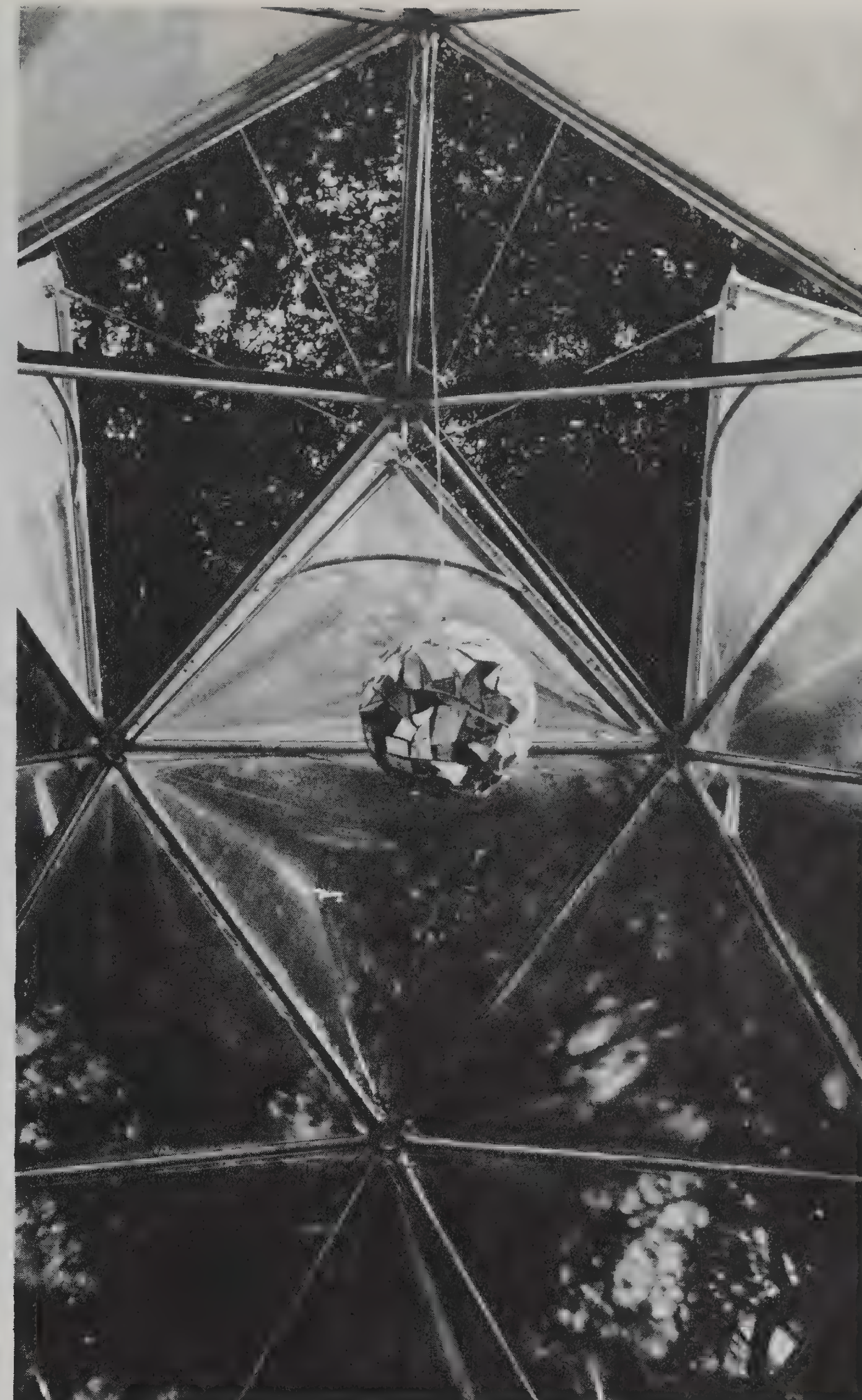


Fig. 12



Inflated panel skin

A way to get a transparent dome that is insulated to an extent is to make the panels from inflated vinyl "pillows". Use 20 mil transparent or translucent sun resistant vinyl, and have the pillows sealed by a pro in a big city. They'll be about $3.00 a panel which compares well with Filon and even plywood after you pay for the paint. These panels will last about three years, but might last more or less depending on sun conditions where you live. They are cut to have the seam weld along the inside of each tube edge, and must have a 2" border outboard of the weld for clamping. These pillows are fastened to the tube frame by impaling them (shingled) over the vertex bolt tips and then clamping them to the frame with half-round strips made from 3/4" PVC irrigation pipe split lengthways in half. Have a sheet metal screw every 6". (A #8 screw is good) This will mean a lot of screwdriver work and drilling, but the result is nice. Blow them up with dry air or nitrogen to prevent condensation. (Fig. 12) See Bubble Dome chapter.

In any of these domes, there are many small details that you must work out for yourself as you go, as there is not a great deal of collected experience to guide you. This information has been proven to work basically. Try new ideas with test sections first.

Bubble Dome

By Jay & Kathleen

How would you make a dome that was completely transparent and still insulated? Glass and other transparent sheet material would have to be used in a double layer to get an insulation effect. That would be expensive, hard to accomplish, and trapped moisture would condense between the layers. There would also be severe sealing problems and possibly even damage to the skin arising from expansion and contraction.

About the same time we were thinking about these problems, we visited Philo Farnsworth and saw models of his proposed spherical dwelling on a pedestal; which featured circular inflated plastic windows. We looked up Vinyl Fabricators in the Yellow Pages. Pacific Vinyl Products in San Francisco made us a test triangular inflated panel from 20 mil sun resistant vinyl electronically sealed at the edges and equipped with an air valve. We tortured this panel with thrown bricks and sharp heavy sticks, but it didn't pop. We exposed it to heat and cold with no serious effects. Fire, however, did damage the vinyl even though it will not support burning. For this reason we decided to inflate the panels with inert nitrogen; it would tend to extinguish any flame puncturing the skin. Dry nitrogen also will not permit condensation inside the bubble.

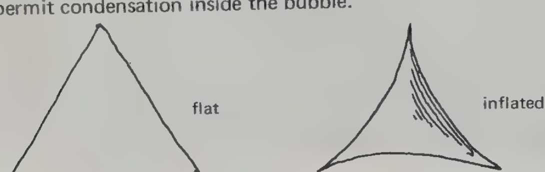


Fig. 1

As we worked with the test panel we discovered that though it was a perfect triangle when flat, it became involuted into the shape seen in Fig. 1 when inflated. This "tendency" turned out to be somewhat more than 200 lbs. at a mere 3 lbs. pressure! This ruled out any possibility of stapling or battening them to wooden frame members. We thought that wood was not appropriate anyway. As we worked on the design it became apparent that the bubble panels trying to deform the frame could be a great advantage. Each bubble would be balancing the other bubbles alongside so there would be no distortion of the struts. But there would be a huge force trying to squeeze the dome in; that is, the struts would be under a great compression load. We thought that this would nicely balance the lift generated by wind, as this load is about 2 1/2 times the wind force push load. This turned out to be the case. Our dome weighs 600 lbs. but is absolutely solid in high buffeting winds.

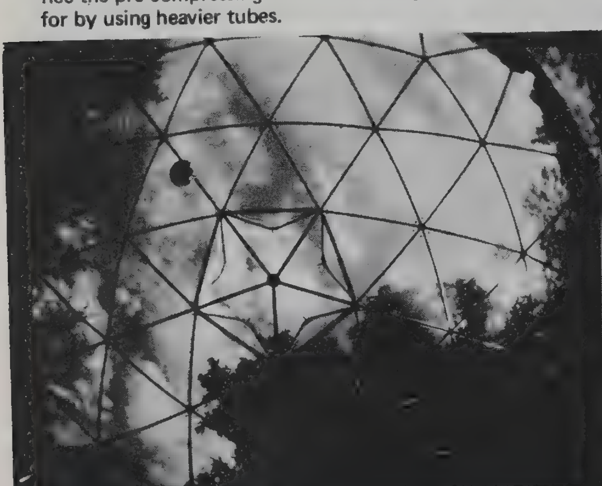
We worked out a clamping strip to hold the bubbles to the tubular struts (see photo, page 22), and also a method of opening the entire top pent by means of springs. We plan to make a dome with all the panels opening in this manner. Imagine being able to open the whole thing by releasing a few ropes! A dome made this way would sacrifice the pre-compressing feature that we just discussed, but this could be compensated for by using heavier tubes.

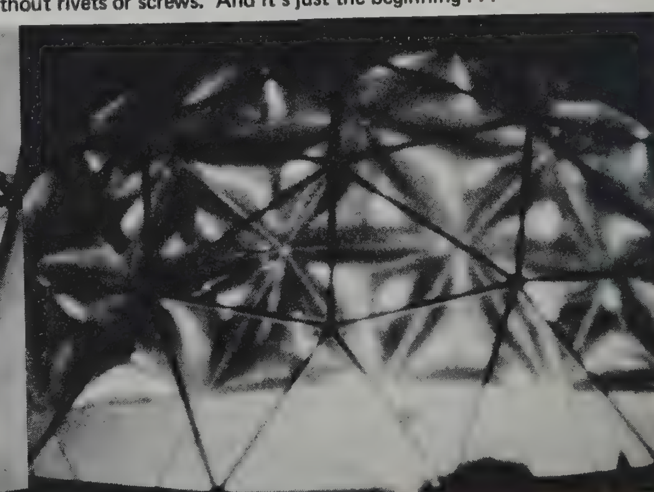
Anyway, we decided to use a tube frame. We made a radial floor, as it was more economical for this size dome. We chose the 20 foot size because it was the largest dome we could make in three frequency, due to the maximum size of vinyl available. We decided to limit our design to three frequency, because a four frequency would use much more tube than was needed for strength. In the photographs you will see that the bottom course is skinned with Filon fiberglas riveted on. This was done because we intended to have a second floor at the level of the top edge of the Filon, and store all our stuff underneath the floor, accessible through a variety of trap doors. The translucent Filon would hide the stuff from people outside the dome, but would let in light. The idea was that when you came into the dome the entire thing would appear to be empty and you could call into being any trip desired, such as a bed, that was stored underneath. This way, the character of the place could be instantly changeable rather than the usual home thing of having your house a sort of museum of mementos from your Mexican trip or funky old immobile and ultimately boring relics. Sadly, the dome proved too small for this play, but we store everything under the bed and can still have a relatively useful changeability in the space. Certainly you notice *people* more in our dome, at least once the unfamiliarity of the dome itself has worn off, which it does right away because we made the shell purposely bare of all special character. The dome itself is only a within-ness inside which we do our thing of that hour. We would never use the Filon again in this way. It booms in wind, and condensation forms on the inside in certain weather conditions. We also don't like the way it looks.

Assembly was easy up to a point. As a test, we did the entire thing ourselves to make sure two persons could do it alone. The floor took one day. The frame went up in three hours. HOWever, the bubbles, installed flat, took some 1300 sheet metal screws and three days. Doing it wrecked our arms and we had no feeling in our fingers for weeks afterwards. Next time POP rivets. We had some leaks, particularly in the top pent opening. Five tries and two weeks later we finally achieved complete waterproofness even in violent storms. The waterproofness is not dependent on caulk, and the flexibility of the bubbles allows for expansion and contraction. We pumped them up from a tank of nitrogen in about an hour of delicate hissing and one near explosion. We finished it off with an insulated rug and a water bed on high enough legs so that we can store all the stuff we aren't using under it. There is a fenced off area near the "door" for taking off shoes so the dome won't be indistinguishable from the muddy fields around it.

It is really nifty to lie there bobbing in our body-temperature water bed and be able to see stars, trees, moonlight, birds, frost forming, snow, rain pelting, and, occasionally, spectators. The many vents keep it reasonable in hot weather. As with all domes it's easy to heat. The main thing is the super feeling of being almost outdoors. No roof, no womb, no hiding place. Just weather out there and you inside. For country living, this is IT. The thing just feels super good to be in. It's hard to imagine getting mad in one.

Next we plan to try an all-opening one, and it may well be a complete sphere while we are at it. We are also working on a production version with many improvements including pop together assembly without rivets or screws. And it's just the beginning . . .





POD DOME

Martin Bartlett

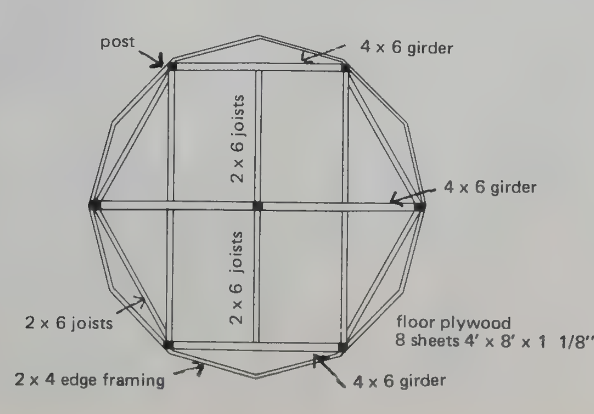
The pod is a dome built out of sheets of fairly thin plywood utilizing the bendy qualities of the material. (Not geodesic) It is very light and economical of material, and should be quite easy to build if you are prepared to cope with the rather unsual problems such a structure presents. It was designed by Bob McElroy and Paul Wingate, and I built mine with no more in the way of plans than some advice from Lloyd who had seen one.

Long pieces of plywood are used. Standard width is 4 feet, and lengths of ten or twelve feet are obtainable in marine grade or occasionally in ordinary exterior grade if you do a lot of phoning around. You are going to have a polygonal floor plan with each side four feet wide. You will need as many plywood panels as there are sides. Needless to say, the size of the structure depends on the number of sides; I used twelve sheets of 1/4″ plywood, each sheet 12′ long. This gave a dome 15′ 5 1/2″ in diameter, with a height of about 9 feet. It is a roomy and pleasant space for one or possibly two people. Larger or smaller pods can be built by using fewer or more panels. The formula for working out the diameter of the dome from a given number of 4′ sides is

$$D = \frac{4}{\sin \frac{1}{2}\theta} \quad , \text{ where } \theta = \frac{360}{\text{no. of panels.}}$$

As opposed to geodesics, in which the larger the better, pods seem best suited to sizes up to about 20 feet in diameter. To achieve a larger space one would need very long sheets of plywood in order to achieve a decent ceiling height within.

Having decided on the size of the structure it is best to build a platform that exact size. Then the plywood can be nailed to the edge of the platform and the rain has no chance of infiltrating itself between the bottom of the sides and the platform. The platform was built in the same manner as those for the geodesic domes with the exception that a strong edge of 2 x 4's was provided beneath the plywood for the skin to nail to. This frame was nailed to the girders and joists which were cut off at the proper angle, and also nailed to the plywood deck. A hole for a trapdoor was left in the platform.

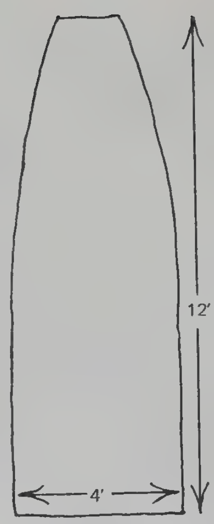


Floor framing plan.

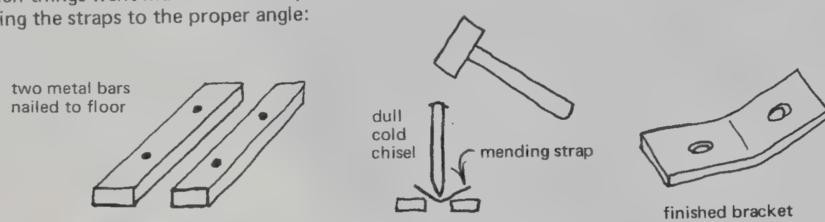
POD DOME *continued*

Each sheet of plywood must be cut to shape before installation. This must be done accurately or there will be gaps up the seams which will cause much heartache, as I can testify from experience. I attempted to calculate the curve at which the plywood was to be cut by a method more ingenious than successful, which led to my having to recut the shape with a sabre saw after I had installed the sides and attempted unsuccessfully to bring them together. The best plan seems to make a model first of as large a scale as possible out of cardboard, and then scale up the pattern for cutting each sheet from that. By all means calculate, by any means your mathematical ingenuity can devise, but confirm your calculations with a model before starting to cut the plywood.

I used 1/4" plywood for the skin. This seems light, and 3/8" would probably be preferable, although harder to bend. The shape of each panel is roughly shown opposite. Needless to say, they must all be identical.

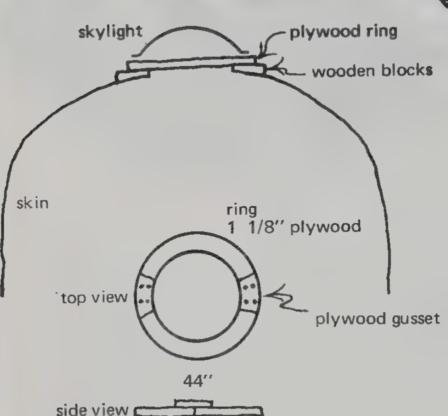


Having cut the plywood sections to shape, they can be nailed to the frame around the circumference of the platform. I also passed a steel strap around the whole structure at the base, expecting that when the sides started to bend down they would have a tendency to spring out at the bottom, but a lot of good nails, especially if they are of the holdfast type, should do the job. At this stage the pod resembles a crown, with the panels sticking vertically into the air. I used the small steel straps known as mending straps to hold the sections to each other. They were held in place by bolts and washers. There was much debate on whether to bend the sections together before fastening or to bend them a little, and then install a ring of straps, then bend more and install another ring, etc., etc. I started out with the latter plan, but found that the straps prevented the dome from assuming a fair and natural curve (this was partly due to the inaccuracy in cutting the panels), so I ended up removing almost all of them, after which things went much better. Jay invented an effective primitive expedient for bending the straps to the proper angle:



When all is fastened together is the best time to cut out windows. This was enjoyable as I had no rigid idea of where to put them, and so would cut out one with the saber saw, enjoy the way it let the outside in and then decide where to cut another. My windows are all rounded shapes, circles, ellipses, etc., which seem to suit the nature of the structure better than anything rectangular. I cut Plexiglas windows and installed them in a rubber extrusion similar to that used to put in car windshields. It is called Lock and Key moulding, and is available from Alasco Rubber and Plastics Corp., 839 Malcolm Road, Burlingame, CA (OX 7-1420). It is not cheap and not particularly easy to install (It seems to have a mind of its own as to which way it wants to bend), but is the best solution I have come across. I am sure it is available elsewhere in the country—get out the yellow pages and let your fingers do the walking.

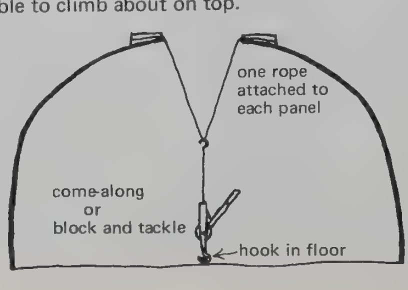
As you may have gathered, there is a hole at the top of the dome. The answer for this seemed to be a Plexiglas dome skylight. This was also expensive (mine, 42" in diameter, cost about $55), but is so beautiful that I thought it worth it, especially since the rest of the structure had cost so little. I got it from Western MacArthur Co., 3150 3rd Street, San Francisco, and they get them from some place in the eastern U.S. and delivery time is 4 to 6 weeks, so foresight is needed.



Pulling the sides of the pod into shape is the most interesting and problematic part of the business. Some means of holding them together at the top is also needed. I decided to use a ring of heavy plywood which would rest on small wooden blocks screwed and glued to the outside of each side panel at the top and would act as a support for the plexiglass bubble skylight.

These wooden blocks were installed before the sides were nailed to the platform. Around each one was placed a loop of nylon rope, the other end of which, also tied in a loop, hung into the dome. A strong hook was screwed into the floor at the center of the dome into which one end of a come-along was hooked. The other hook of the come-along held the ends of all twelve nylon ropes, which it seems important to cut to exactly the same length. As the come-along was winched down, the tops of the panels bent over and the hole closed like the petals of a lotus. Or, since I was learning how by doing, it should work perfectly for you!

When the dome is closed down, the plywood ring can be screwed to the blocks at the top, and this will hold everything in place while you install fastenings up the seams. Not too many of these are needed: I used one every three feet or so and the structure seems quite rigid. It turns out to be quite strong—even though without a frame and built of such light material, it is possible to climb about on top.

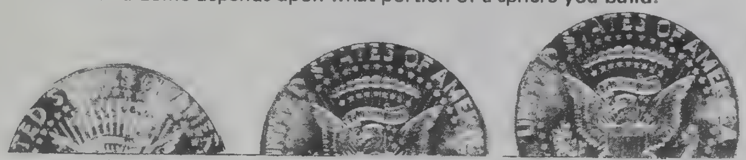


If your panels are cut accurately (how often I return to that theme!) a variety of finishes could be used for the outside. [One day we came to see Martin as he was trying to make the plywood meet and he greeted us: "Welcome to the temple of accumulated error."] I ended up with these embarrassing gaps and so decided to cover the seams with vinyl (on the outside), swath the whole structure with roofing paper, and shingle it. I used about three squares of #3 cedar shingles (approx. $14 per square), and stapled them on in eccentric patterns using 1/2" monel staples, which only occasionally came through to the inside. I have lived in the dome during December, January and February in the mountains, and have lost only one shingle. The appearance of the dome has been compared variously to pine cones and owl feathers, and I am delighted to have such a shell to protect the seed of my developing consciousness.

Costs

Costs per square foot are deceptive, especially since in domes you usually build lofts, and are not confined to the floor. Costs per cubic foot are a far better measure of value.

Total cubic feet in a dome depends upon what portion of a sphere you build:



3/8 hemisphere 5/8

Here are costs for 1969-70 of three different types of domes we have built. *Materials only—does not include labor.*

Pacific Dome

24′ diameter 5/8 sphere plywood dome
Floor area: 452 sq ft
Volume: about 4500 cubic ft

Floor		
frame		$110.00
plywood		124.00
	Floor cost	$234.00
struts: total about 800 lin ft @ $380/1000 Bd. ft		160.00
plywood: total about 30 sheets @ $8		240.00
nails		25.00
hubs		15.00
straps, buckles		35.00
vinyl		20.00
caulk		35.00
paint		25.00
wood for window batts		20.00
misc.		30.00
insulation		90.00
	Total cost	$929.00

Bubble Dome

20′ diameter 5/8 sphere vinyl pillow dome
Floor area: 314 sq ft
Volume: about 2600 cu ft

Floor	about	$160.00
conduit		65.00
vinyl pillows		225.00
inflation (nitrogen)		5.00
springs, bolts, nuts, etc.		20.00
Filon panels		96.00
alum angle		30.00
PVC pipe for clamps		26.00
lightning rod		5.00
misc.		20.00
Fig Newtons		12.00
	Total cost	$664.00

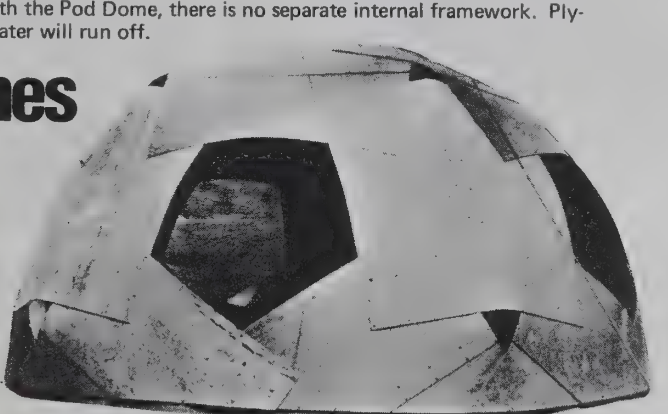
Pod Dome

15′ 5 1/2″ diameter, bent-over plywood dome
Floor area: 185 sq ft
Volume: ?

1 1/8″ tongue and groove plywood for floor, 6 sheets @ $8	48.00
misc. 2 x 6 and 4 x 6 joists and girders, 4 x 4 redwood posts, approx	35.00
seven concrete piers @ .75	5.25
12 sheets 1/4″ x 4′ x 12′ ext. grade plywood @ $7	84.00
one bubble skylight and one bubble window	75.00
Plexiglas for windows	14.00
rubber moulding for ditto	18.00
3 rolls building paper	9.00
3 squares #3 red cedar shingles @ $14	42.00
nails, staples, bolts, mending straps and misc. hardware, say,	20.00
	350.25

Simple, cheap, quick to build, plydomes are made of bolted-together sheets of 1/4″ or 3/8″ plywood. As with the Pod Dome, there is no separate internal framework. Plywood is shingled so water will run off.

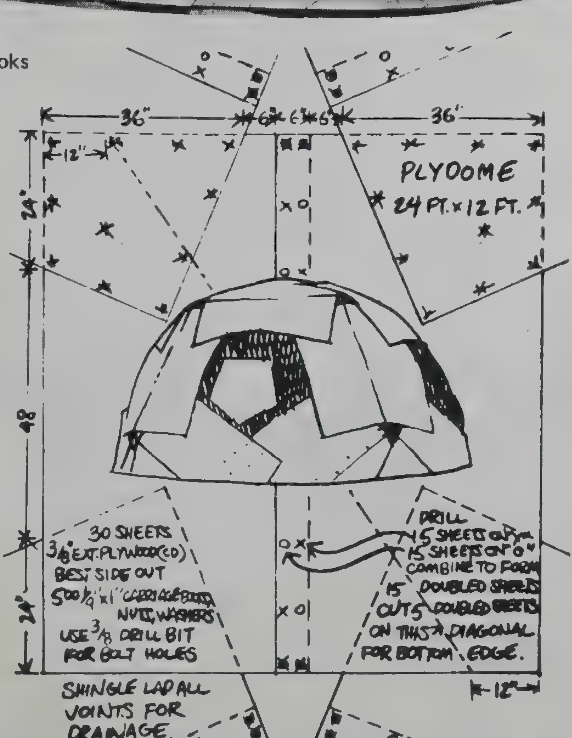
Plydomes



We've never built one, but it looks as if leakage would be a major problem. You should prime and paint plywood carefully before assembly, including edges and bolt holes, and either caulk or use a neoprene washer where bolting together. Window details should be carefully considered.

Try it in model form first. See also Fuller's patent on plydomes.

People from Canyon, Calif. sent us these plans:



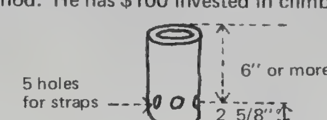
I often think of a dome as a boat hauled ashore and turned upside down.

Like a ship, a dome has a mast.

The mast goes at top center, projects 6″ or more above the dome, and gives you something to throw a rope over when climbing on the exterior (which will be often).

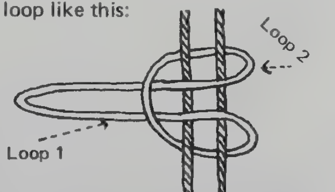
Bill Woods taught us this method. He has $100 invested in climbing equipment—it's a long way down.

We made our masts like this:



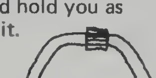
Mast

The *6″ or more* part is what you throw the rope over. Look in mountain climbing catalogs for the equipment: a good 1/2″ nylon rope—Goldline is o.k.; Edelreid Perlon is better. About one yard of a slightly smaller diameter rope (or nylon strap). Tie ends together to form loop like this:

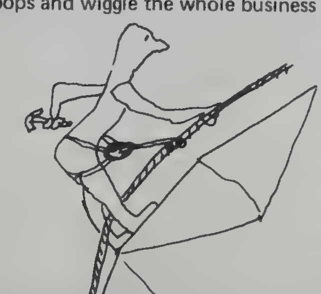


It's best to take loop one around again and come through loop two again—for double protection. This knot will slide when no pressure (weight) is placed on it, but will tighten, and hold you as soon as you put your weight on it.

Carabinier with safety lock:



Harness: You can buy a ready-made harness or make one out of about two yards of nylon strap from a mountain climbing shop. The ends are tied to make a continuous loop. To get into it, hold the entire loop horizontally behind your ass and bring the loop ends together in front of your crotch. Hold them with one hand and reach back between your legs with your other hand to grab the lower line. Pull this line between your legs to meet with the other loops in front. Hook the carabinier through all three loops and wiggle the whole business up to waist level.



When you lean back, the knot holds. To move, you take weight off the knot. When you get to desired position, lean back, and you can work with both hands free. It's a strange sensation—you'll gradually learn to trust the rig. It works best to start at top, and work your way down: you get so you learn the amount of relief needed to descend, and soon you're walking up and down on the domeskin. Have care not to slip feet up-head down; you'll fall out of the harness.

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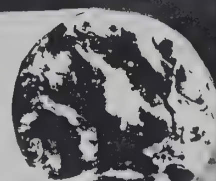
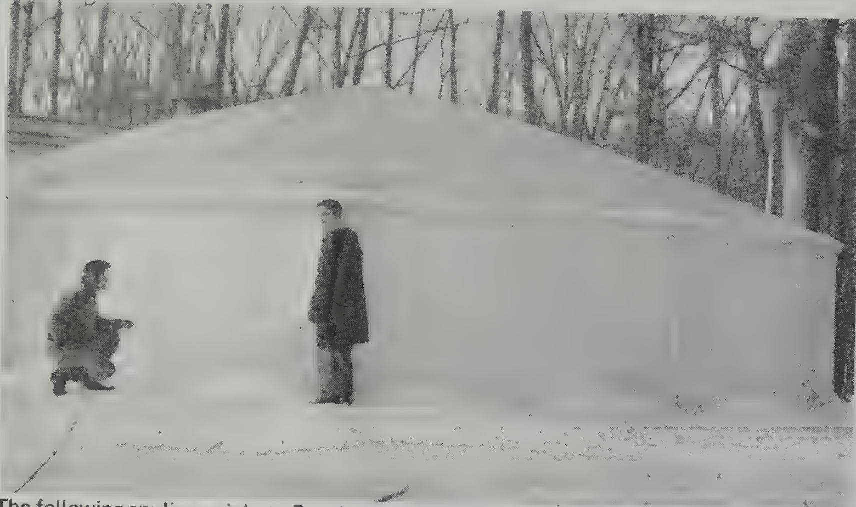
R. Buckminster Fuller



PARADOME®

The Paradome® is a patented lightweight dome structure developed in Ann Arbor, Michigan by Bill Moss, who also developed the O'Dome and the PopTent. (The PopTent is a two-man car camping tent sold by Thermos that can be put up in one minute without ropes, poles or stakes.) This dome is particularly well suited for conditions calling for a light shelter with rapid erection and takedown, but where the floppiness of a tent would not be good. The Paradome can be set up or taken down by two people in about a half hour. It will withstand hurricane velocity winds and heavy snow loads if designed to do so. Weight depends on the materials used; strong 15 footers have been built that weighed less than 100 lbs. The largest attempted so far is 400 lbs, 40 foot diameter.



The following applies mainly to Paradomes up to 15' diameter. Larger ones use the same principles but will require the custom development of construction details.

The paradome consists of three main assemblies: the wall, the roof struts, and the roof skin. Walls of production Paradomes have been made from FomeCor sandwich and other plastic boards. Any reasonably rigid panel material can be used, even heavy plywood. Panels can be any convenient size. As a rough guide, a 15' diameter Paradome has been nicely made from sixteen 36" wide by 5 1/2' high boards. They are hinged to fold "flip-flop" by conventional hinges, "living hinge" polypropylene strips, tape, sheet metal "stovepipe" joints, and in the case of cardboard or FomeCor, scored lines in the material. Hinges can be made waterproof with wide electrical tape. Near the upper left corner of each panel is a #4 brass grommet to accept the roof strut. It is placed about 3" down from the upper edge and as close to the hinge as is reasonable for strength. In a similar location at the bottom of each panel is another grommet for staking down the dome. Remember when choosing a grommet size that the roof tube goes through it at an angle. The tools are available for about $6.00 from a tent and awning shop if you can't borrow them. The free ends of the wall strip will have to have a way of being fastened together. Easiest is to allow a 3" overlap there and bolt every foot through matching grommets with 1/4" bolts, large washers, and wingnuts.

The roof strut assembly consists of a hub, radial tubes, a tube tip detail that accepts a cable and the edge of the roof skin, and a perimeter cable. Unless you have casting facilities available (a sculpture studio will do), the easiest way to make a hub is to weld round stock steel pieces together into a regular *rigid* star of the required number of points. If you are using tube of an .058 to .060 wall thickness (about 1/16"), make the hub projections from stock 1/8 less than the outside diameter of the tube (e.g., a 5/8 tube would use a 1/2" hub projections.). The hub projections should be about 2 1/2" long for smaller domes. For larger domes, the projections or even the basic design of the hub wll have to be experimental. An automobile wheel makes a good base for a large hub.

The best material for the roof tubes is aluminum alloy 6061T6. Electrical conduit will not work. For domes up to 12 feet, use 5/8 outside diameter tube with .060 wall. Larger domes need larger tubes. Our 40 footer used 20 pieces of 1 1/2" tube with about a 1/8" wall. Tubes should be cut somewhat longer than the proposed diameter of the dome so that they will bulge up into a dome shape when squeezed by the cable to the diameter of the wall circle. The amount of bulge should be sufficient to shed snow and not pop inwards under wind load, but should not be so great as to "jello" back and forth. Trim a *little at a time* off the tubes until the desired bulge is reached. A little trimming makes a great difference, so go easy. The tubes are drilled or slotted at the tips to receive a 1/8 aircraft cable. The cable is indoors resting on the wall. The tube tips project through the walls about one inch. Though there are other ways to do it, the one shown in the illustration works well and is easy to do. Two tip details are shown in fig. 1 & 2. Small domes with stiff walls don't need a cable and can use a tip detail as in fig. 1.

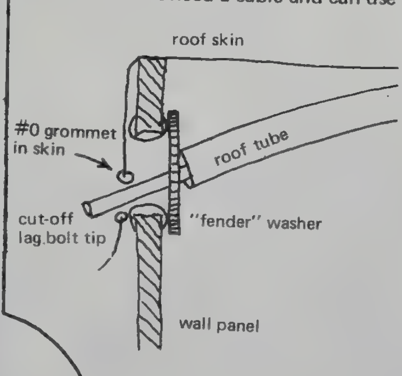


Fig. 1

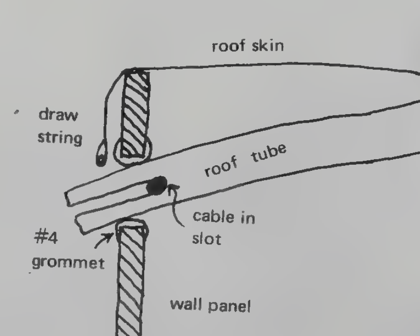


Fig. 2

To assemble, slip the tubes onto the hub and thread the cable through the holes or slots at the tips. The cable should have an eye called a "thimble" at one end, and a turnbuckle with a hook at the other. The turnbuckle will allow adjustment. (Rope will not work; it stretches.) On larger domes, you will have to use a fence tightener, a "come-along", or a small block and tackle to draw up the cable. Insert tips into wall panels as you unfold (see photos).

When they are all into grommets, fasten the wall ends together. If there is any wind, you will need lots of help for this. Stake it down from the inside at this time with fittings bent from heavy wire. (Fig. 4) The stakes prevent both lift and kicking in at each wall joint.

The roof skin can be canvas, vinyl, or polyethylene (if you don't care about long life). For permanent use, make the skin from a premium coated fabric such as Hypalon or Acrilan. Fabrics and vinyl will be cut into gores patterned on the actual assembled roof struts. Fabric should be sewn on an industrial sewing machine using dacron tent thread. Vinyl should be 20 mil sun resistant grade electronically sealed by a professional shop. It might have to be sealed in short straight lines, but this will work out all right because the curve is not really very curved. All skins should be patterned so that they overlap the top edge of the wall panels at least four inches. The skin can be fastened to the roof tube tips in several ways. One is to have a drawstring running in a tunnel all the way around the skin. (Fig. 2&3) Another way is to have large grommets in the skin that will fit over the tips. The area around the grommets should be reinforced. Smaller grommets can be used if the tube tip is first made smaller by plugging it with a dowel, screwing a lag bolt into the dowel, and then cutting the bolt head off, leaving a small diameter tip protruding from the tip of the tube. (Fig. 1) In any case, the roof should be a tight fit. Remember that many skin materials will shrink, expand and contract as the weather changes. For this reason, the roof skin should be fitted at the temperature most likely to be encountered by the structure. If the Paradome will be used under a wide variety of conditions, the drawstring is probably best. A polyethylene roof can be made in one piece by cutting a circle and then cutting a pie out of it sufficient to make it nearly conform to the tube contour. Then cut another smaller bit out near the hub to make it lie down there. Poly can be taped together at the seam. It is best to use grommets with poly. Apply them through a tape reinforcement. Poly can also be held down with little ball-and-choker doo-dads available at the lumber yards that sell it.

To prevent condensation inside the dome, you will have to use a ground sheet such as heavy polyethylene. Vents and door details will have to be worked out according to what makes sense with the materials you have used for the walls and the use expected. You probably won't need windows because the translucent roof lets in plenty of light. Flaps made from Filon make good vents. They can be taped on, as can plastic screens if necessary. Paradomes fit together in groups too, by fitting them door to door to make multi-room structures. The basic idea of the Paradome hasn't been fully explored, so there is good opportunity for experimenting.

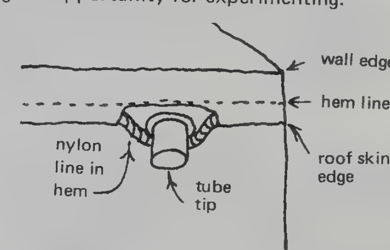


Fig. 3

Fig. 4

floors

The floor of a dome should be carefully considered. We will describe concrete, wood, and some experimental floors.

CONCRETE FLOORS

Concrete seems to be the most practical floor for domes. It's cheaper than wood, provides a good anchor for the dome, and with proper precautions doesn't have to be icy cold. You need level ground for concrete, and if you're on a hillside, it is usually better to build a wood floor, rather than cut into the hillside with a bulldozer. However, if you decide upon concrete, here are some simple basic instructions that will be helpful. I have never been able to find anything written on how to pour a concrete floor. If possible, find someone to help who has been through the process.

Typical concrete floor

–typical concrete floor is 4" thick, reinforced with 6" x 6" x 1/4" steel mesh. 3" thick floor is strong enough, however.

–perimeter of floor is thicker, as dome weight is there.

–1/2" reinforcing steel goes around footing; it should be suspended above ground (tie it with wire to rocks). (See fig. 2)

–gravel underneath for drainage, and to provide solid, level place for concrete slab to rest on.

–plastic sheet important as vapor barrier. Put it over the gravel and under everything else.

–hooked end of anchor bolt is imbedded in the concrete. Use two or three 1/2" x 10" bolts for each strut along bottom of dome.

Remember that if you are making a 3-frequency, 5/8 sphere dome, the bottom course is not level.

Fig. 1

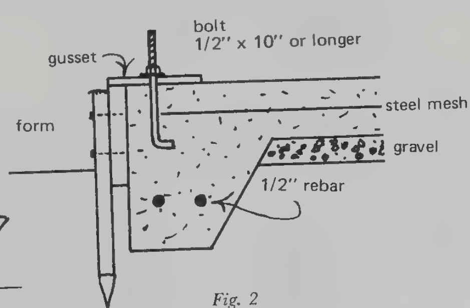


Fig. 2

Therefore you will have to adjust the height (and length) of your bolts accordingly. Hook end should go at least 8" into concrete. Distance between edge of concrete and bolt should be *at least* 2 1/2".

Preparation for pour

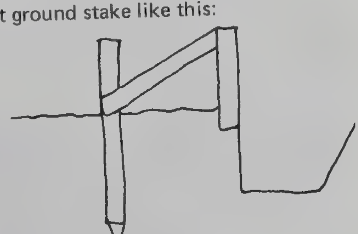
The ground must be level. If possible, rent a transit–it will save much time. The transit is a level on a tripod with a small telescope. (See Wood Floors, fig. 2) It is placed in a central location, firmly fixed, leveled, and then each point you shoot through the telescope, going in any direction, is at the same level. Once it's leveled be careful not to bump it. One man holds a measuring rod or tape measure, another shoots, and you find out differences in elevation.

Find the low spot, then drive many stakes indicating how far down you must dig to bring the rest of the ground down to the same level as the low spot. Throw the dirt you dig outside the floor perimeter–you don't want to pour concrete on loose fill.

Try to get ground to within an inch or so of being level. Gravel will help level it out even more precisely.

Forms

You can rent steel stakes for forms–very useful. In soft ground stake like this:



If form starts to give when pouring, pack dirt behind it.

If it is your first dome, it is somewhat risky to pour the floor before the first course of the dome is erected–once the concrete sets, with bolts in it to tie the dome to, you can't make any adjustments. Therefore, if you're not sure of the precise diameter, you may want to erect the first course to get the exact floor diameter.

An alternative method to building forms, although I haven't tried it yet, is to use the bottom edge of the extra large base triangles as forms. Erect first course of dome, arrange it so that center of each ground strut is an average equal distance from center, get each of the five hubs touching the ground to be at the same approximate level, and stake it in place so that it can't move back and forth, or up and down. Leave an opening to wheel concrete in. Drill holes in the struts, put anchor bolts in place, and prepare floor as above.

Positioning forms

Still using transit, position form (or bottom course if you do it that way) so that it's level. With form, top of wood is floor level, and concrete is poured up to that level. With bottom course as form, run a strip of wood level with bottom–resting hubs along plywood (see fig. 1), and pour concrete to that strip. (A pencil line doesn't work as it gets splashed with wet concrete and you can't see it.)

Once you have a level to pour concrete against, anchor bolts in place, plastic on ground, gravel down, steel mesh on top, reinforcing steel in trench, etc., you're ready to pour.

Estimating materials

You can either mix yourself or order a ready-mix truck. The sand-gravel mix, or the concrete comes either by the cubic yard or by the ton.

–to change cubic feet to cubic yards, divide by 27

–to change cubic feet to tons, divide by 20

–to find cubic feet of floor volume: multiply .7854 times diameter squared (.7854 d^2) and multiply by the depth in feet (4/12 if 4" deep floor)

–to figure content of footings (ditch around perimeter) multiply width of trench in feet (as 8/12 for form 8" wide) by depth of trench in feet (as 16/12 for a form 16" deep) by the length of the trench (circumference of dome)

–perimeter of circle: $2\pi r$ (2 x 3.14 x radius)

add total for floor to total for footings to get total cubic feet of cement. Convert to tons or yards.

Home mixing

If you mix yourself, convert to tons and use the following table to determine how many sacks of cement to order, depending on how rich a mix you use. (1:2:4 is common for floors–that means 1 part cement/2 parts sand/4 parts gravel)

Mix Proportions

cement	sand	gravel	total mix of these	constant
1	2	3	1:5	4
1	2	4	1:6	3 1/2
1	3	4	1:7	3
1	3	5	1:8	2 1/2

Rent a mixer and a contractor's wheelbarrow with pneumatic tire for transporting concrete from mixer to floor.

Have a hose and two buckets and while shoveling into mixer let water fill buckets. You'll soon learn proper amount for dumping into mixer. The less water the stronger the concrete.

A regular size mixer will take about 18 shovels of sand and gravel, 3 cement, and that's about the right amount for a wheelbarrow load.

Pouring

Three is a good size crew. One on mixer or guiding chute from truck, two working with concrete, alternating on wheelbarrow and leveling. Have at least two finishing trowels ready. If weather is hot, concrete will set fast. Rub some lemon juice on your hands before starting; it'll help protect your hands from cracking from cement.

Dump concrete in place, screed off level.

Keep checking anchor bolts so they're upright, and at proper height to grab ground struts. After concrete is dumped, reach in with your hands and pull mesh up so it's not just lying on the ground, but is in the middle of the slab.

When you stop for lunch, clean all tools off.

Take a stick and puddle the footings . . . poke concrete up and down to fill any voids in the trench.

Ready-mix

If you order ready-mix, you must be prepared to work fast, especially if the weather is hot. If the truck cannot back to within about 20 feet of the site (he has chutes that long) you either have to build additional chutes, or wheelbarrow it from the truck, and you may need ramps. With heavy wheelbarrows-full, have a helper running backwards, holding the front. Main thing is to be prepared before the truck arrives. Have the driver check the site beforehand. You usually get about 45 minutes per truckload, before they start charging for overtime. Let the driver run the pour–he'll inevitably give the best directions for concrete placement.

Screeding

This is a very important part of pouring a concrete floor and you should be prepared in advance. I've never seen it mentioned in a book. The problem: once you start pouring concrete, you must have a quick means of bringing it to an approximately uniform level. The solution: you use a 2 x 4 and at least two stationary boards, fixed at finished floor level. As the concrete is poured, two men move the 2 x 4 back and forth–wading through the concrete with rubber knee boots on–and it levels the concrete, ready for final troweling later. See fig. 3.

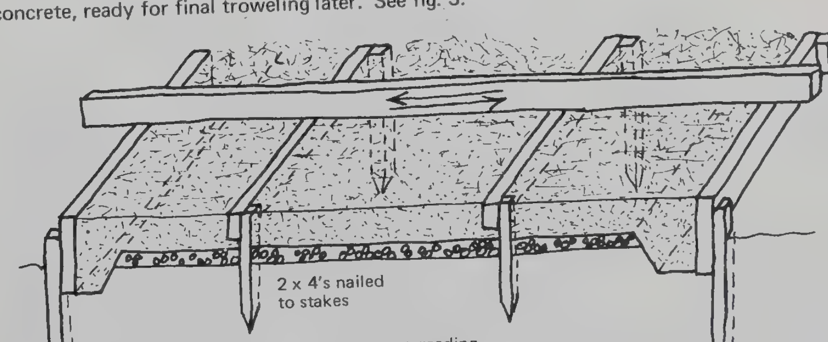
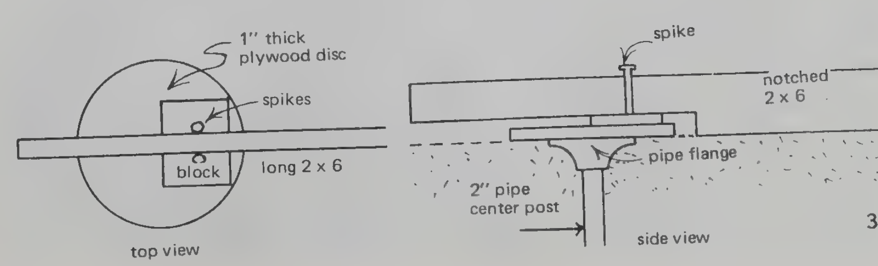


Fig. 3

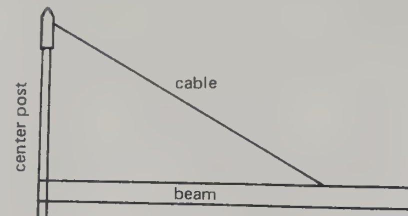
Another way to do it is with a center post.



FLOORS *continued*

Once all concrete is poured and floor is screeded, you remove the 2 x 4's and stakes or post and fill in with concrete. Floor is now ready for troweling.

Bill Woods has designed and patented a motorized concrete screed machine (U.S. Patent No. 3,367,083) that looks like this:



If you're going to pour a number of floors, see Dyna Domes about getting a license to use this machine.

When the floor is all poured and screeded, finish with trowels. I never learned to do this too well. I believe masons sprinkle a little cement on the top if there's too much water, and to get a smooth hard surface—they then trowel it in. Keep working with the trowels until it looks o.k.

Clean all your tools, the mixer, the wheelbarrow with a strong hose stream. Get concrete off your shoes, and hands and put a lotion or oil on hands. You'll probably be so tired you won't be able to sleep.

1" concrete floor: this floor and others are described in Ken Kern's *The Owner Built Home* (see bibliography). I tried a 1 1/2" floor, and it worked well. The unique feature here are long 3' concrete spikes (like ladies high heels) that go into the ground every 3', and an air space that develops between floor and ground, providing insulation.

WOOD FLOORS

The first floors we built were square. We used prefabricated concrete piers every 8' on center. The floors were simple to construct, and students with no previous building skills were able to build floors with almost no experienced supervision. Prime disadvantage of a square floor is that the dome is round and the floor corners protrude from underneath the dome. We had trouble with drooping areas in the floor where we had the dome stick out beyond the main braced part of the platform and then tried to bridge the resulting gap with unbraced plywood flooring. The general floor plan shown includes piers and beams to prevent this.

Jay worked out a radial floor for his 20' dome—a far better approach, described in another section. It might pay to work one out for your dome.

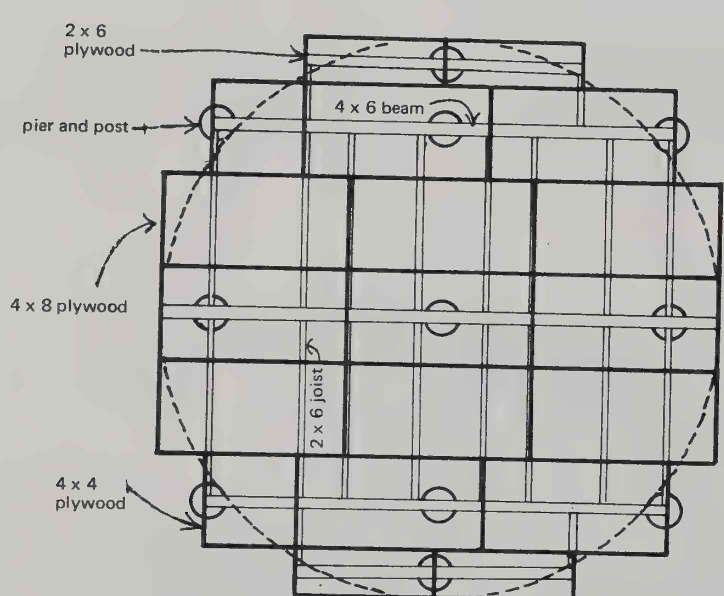


Fig. 1

Square floor

General Description

For the 24' dome, piers are placed as shown in Fig. 1 on 8' centers except for the two extras at the sides. The posts, cut to whatever length is necessary to make the floor level, support 4 x 6" beams to which 2 x 6" joists are attached (flush) with joist hangers. The flooring is 1 1/8" tongue and groove plywood with exterior glue called "2-4-1". It can span four feet and is the only flooring used. We'll describe the square floor, as the building steps might prove helpful. Remember that this is the minimum floor, and it might not meet local building codes. It must be diagonally braced, and it should be securely anchored to the piers with metal brackets if you live where there are high winds.

Instructions

Start by setting up the transit (it can be rented) where you want the center of the floor to be. Drop the plumb line from the center of the underneath of the transit. This will mark the center of the center pier. The transit has a 360° dial. Lock it at 0° with it pointed in the general direction of the next pier. One man sights through the transit, two others hold a long measuring tape to locate the proper distances from the center pier, and a fourth man drops another plumb line at that proper distance to mark the location of other piers. (Fig. 2) For the floor shown these distances will either be 8' or 11' 3 3/4". The plumb line man stands at about the right place for the next pier

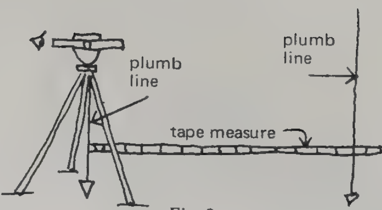


Fig. 2

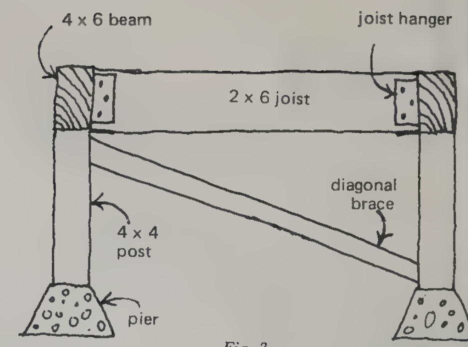


Fig. 3

and dangles the bob (steadily) at the distance from the transit determined by the tape measure men. The transit man lines up the string from the plumb bob in his instrument's cross hairs. When it is aligned, drop the bob and mark the spot locating the pier. Unlock the transit and swing it 45° and repeat the same process. You will alternate between the long and short distances. Shoot the location for the two extra piers at the same time as you shoot the others in that line.

At every marker, dig down to hard dirt. Make plenty of space so you can shift the pier around a bit. If you live in cold country, the pier will have to be made in a way that works for your climate. Ask around. Place piers, except the center one, and re-check with transit. Take care to do this right or you will be extremely sorry afterwards.

Cutting posts

The transit, still in place, is used to determine the height of each pier. Aim at the pier and have a man hold a tape measure vertically up from the center of the pier. Write down the measurement, which is the number that you see at the cross hairs. Unless you want the floor extra high, assume the highest pier to be zero—you'll rest a beam directly on it without a post. By subtracting, you can easily determine the necessary height of each post, with the exception of the center one.

Framing platform

Remove the transit and put it away to prevent damage. "Toenail" post to piers, leaving nails out a little in case you have to shift things around a bit later. Install beams on top of the posts and toenail them on. You might have to have helpers hold them to keep them from falling over. When the center beam is placed, you can measure for the center post, cut, and install it. As you nail on the beams, use two levels on the posts to make sure they're straight up and down. Beams should be installed with any warp humped upwards so that the weight of the floor will tend to straighten them.

Joists should be pre-cut to the proper length—allowing for the thickness of the beams, remember. Install the joist hangers on the joists using the special nails that come with the hangers. Mark the beams for joist location, keeping in mind that you want a joist to support the edges of *two* plywoods: that is, two plywoods will share a joist and meet halfway across its thickness. It's easy to goof this up. Think it out carefully and double check measurements. Nail joists in place. Get onlookers to help. (Bring extra hammers.) See. Fig. 3

Installing Plywood

Start with the middle piece and move out. Use 8d hot dip galvanized nails spaced about every 6". Bash the tongue into the groove using a sledgehammer with a block of wood between it and the fragile plywood edge.

Diagonal braces

While a man checks each post for verticality, hold a 2 x 4 as shown in fig. 3, and mark the angle at which it must be cut. Install with toenails.

Anchors

Rectilinear houses are often built on piers, with no footing, and no connection to the ground other than the tremendous weight of the structure: gravity does the rest. However, domes are so light that they should be anchored securely to the ground. This can be done by substituting poured concrete footings for the piers described above, or screw-in type anchors and cables. (See Wards or Sears Farm Catalogs)

EXPERIMENTAL FLOORS

Fuller has made floors by grading the site, applying a layer of gravel for drainage, and then laying a floor membrane consisting of (starting at the ground) a layer of corrugated aluminum, a layer of Celotex or similar soft board for insulation, and topped with 1/8" tempered Masonite. This material should be layered so that no joints between panels come right over one another. The layers should be cut to fit *inside* the dome so that the finished floor is above grade; that is, above the level of the surrounding land. This floor has the advantage of being reuseable. Under some conditions, a heavy polyethylene sheet can be substituted for the corrugated aluminum.

A recent conversation between Jay and Fuller generated this idea: Dig a shallow round pond, line it with polyethylene, and float a floor made from thick styrofoam planks like a floating dock. If the dome were light enough, it would be possible to easily rotate the dome to face the sun. It would automatically be level.

In any case, it is necessary to have a waterproof membrane under the dome or you will get severe condensation inside the dome even with large vents.

FLOORS *continued*

RADIAL FLOOR CONSTRUCTION

adial floor construction is in many ways easier than regular construction, and for rtain sizes of dome it saves lumber. It has the added advantage of being buildable one person, and does not require the use of a transit. You will need a heavy hammer, saw, a level, two pieces of wire and a small 30/60 triangle. You will also need a couple fistloads each of 16d and 8d nails, and flat joist hangers for as many beam ends as ou are going to use. The number of beams and other parts that you will need can be etermined as follows:

o find out if a radial floor is useful for your dome, get some 1/4" graph paper and all each square 3". This makes every four squares a foot. If you will be making a ome that will run off the paper, carefully tape some pieces together. In the center f the paper strike off a circle of the size of the intended dome. Use the intersection f "foot" squares as a center so counting will be easier. If possible, a hexagon frame hould be used, as it is the easiest to make and measure. You could make as many adial beams (the beams coming to the center point) as there are sides in the dome, ut that will mean 15 piers for a 3-frequency dome—too many? The hexagon points vill protrude out from beyond the dome. We recommend that the dome be ON the latform rather than hanging down over it, as the sealing is easier.

ay out 4 x 8 panels on the floor plan of your intended dome in a pattern that makes ense. Remember if you are using 1 1/8" plywood to keep the tongue and grooves neshing properly. See if you can do it in a way that the cut off plywood ends can be verturned and used upside down at the other side of the dome to fill in the empty paces. Also, if possible, arrange things so a whole 4 x 8 will bridge the beam nest over he center pier, as shown. Scrap A is turned over and used at B, locating edge P as hown in Fig. 1. For a 20' dome this can mean that you can make the platform from only 11 sheets! (see drawing). Also, space the plywood so that the edges arrive over beams in the strongest manner. If it all works out well, you will save wood and piers.

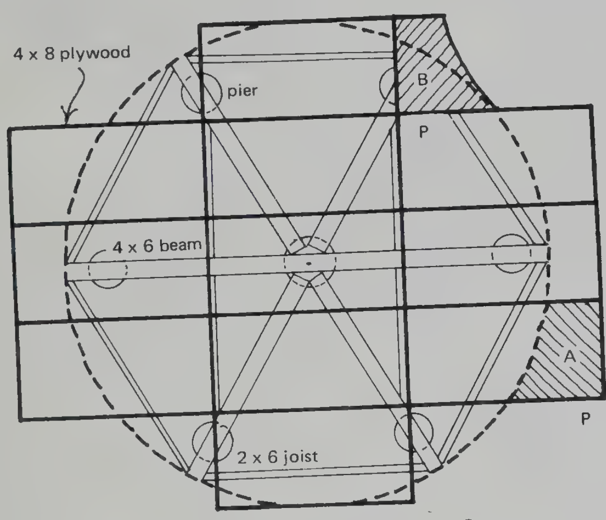


Fig. 1

Instructions for Hexagonal-Frame Floor

(If you use an octagon or other shape, it will be the same except for the angles.) Determine the highest point on the building site and install a pier there. Use whatever method of footing that is useful in your climate. Take a 4 x 6 beam that is as long as your floor span and rest its tip on this pier with the other end out in the air over the lowest part of your site. Install another pier near that tip. You can put the piers as far as two feet inboard from the beam tips if you want to. Now put a level on top of the beam and raise it up at the lower end until it is level. Dangle a ruler down to the lower pier with one hand and note the distance. Set the beam down; cut a post that length; install it with toenails. Also toenail the first end of the beam to the first pier. Make very sure that this beam is level as installed. If necessary, prop it so it doesn't fall over. Now. Make a mark at one end of the beam and measure to the other end exactly the size that you want the floor to be (diameter). Make these marks in the *center* of the beam, and drive nails in them. Now make a mark at the very middle of the beam at the halfway point. Drive a nail in it. Right under this mark, install the central pier and anchor it well, either by digging deep, or with concrete. If the ground is soft, make this a big one. This post should be large enough to accept all the other radial beams. Toenail it well and make sure surface is level. See fig. 2.

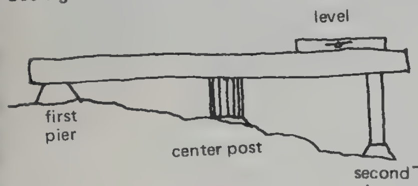


Fig. 2

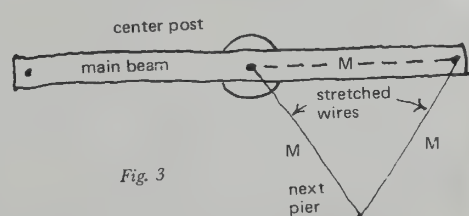


Fig. 3

Take a piece of floppy wire that won't stretch and make two pieces with a little loop at each end so that when the loops are put over nails the piece is *exactly* the distance from the halfway center point on the main beam to the nail driven in at the tip on the distance mark you made there (distance M in Fig. 3). Loop one end of a wire over the halfway center point nail, and one end of the other over the nail near the beam tip. Stretch these wires out in the general direction of the next leg of the hexagon you are making. When both wires are tight and the loops in your hand are together, this is the place for the next pier. Put one there, or slightly inboard, according to where you put the piers for the main beam. Take a 1/2 beam and draw a short line on it exactly in the middle lengthways as if you were going to split the beam into a 2 x 6 from the 4 x 6 it is. Line this line up with the main beam halfway center point nail with the 1/2 beam resting on the center post and up against the main beam (see Fig. 4). Go to the far end, put on the level and measure how long a post you'll need, make it, etc., etc.

Measure with your wire from the main beam halfway center point out on your new beam, and drive a nail in the loop, centered on the beam surface. If you're making a hex, the distance from this nail to the nail on the tip of the main beam will also be the same. (The distance in a regular hexagon from tip to tip is the same as from center to tip.) Now you are ready to make a perimeter joist from 2 x 6. Because of the thickness of the radial beams, the perimeter joists are not exactly the length of the wires. With a wire stretched from tip to tip over the position that the perimeter joist will occupy, measure the distance (a) in fig. 5 and subtract twice this (once for each end)

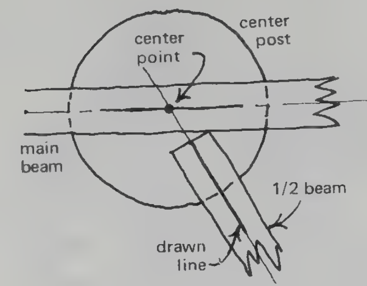


Fig. 4

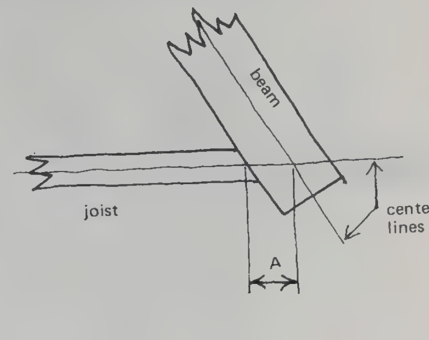


Fig. 5

from the wire length (M) to get the "true length" *at the center line* of your perimeter joist. (M minus 2A) Because of the angle cut, the perimeter joist will actually have to be CUT longer than this. Take the 2 x 6 and draw a line on it at 60° near one tip. Also draw a short line dividing the joist in half lengthways as if you were going to split it into 1 x 6). (See Fig. 6) Where this line intersects the angle line, make a mark. Measure from the mark down the joist to the other end the distance you have already found to be the true joist length (M minus 2A) and make another mark in the center of the joist. Using the triangle again, make a 60° angle line (the opposite way than at the other end, please) so it intersects this mark. Check again. Cut the joist and six more like it. Set the other piers and beams, marking the true beam lengths with the wire and marking them so that you can tell where to install the perimeter joists accurately.

The perimeter joists are attached to the radial beams with straight joist hangers first bent at the 5 1/2" line at 90° and nailed to the radials. The perimeter joists are then rested on the bent hangers and the hangers are beaten with a heavy hammer until they wrap around the perimeter joists. They are then nailed in place there, too. When all the beams and joists are in place, start at the center with the plywood and begin to nail them down as you have planned on the graph paper. Where non-tongue and groove edges meet in air, install more 2 x 6 underneath. Do this also where the span seems to make the floor too bouncy. Don't span more than about ten feet with a 2 x 6 used this way.

When the floor plywood is all nailed down, strike a circle the size of your dome on it using one of your wires from a center nail. Cut off the corners with a Skilsaw or chainsaw *(carefully)* and take the pieces to the right places to fill in the gaps. Trim the whole thing off neatly. NOTE: The legs will have to be braced for side-to-side motions AND a screw-it-into-the-ground radial rotation motion called "torque".

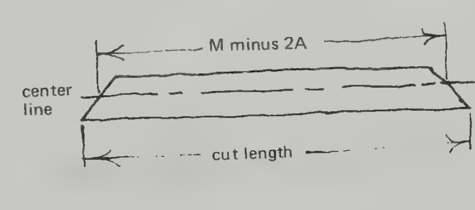


Fig. 6

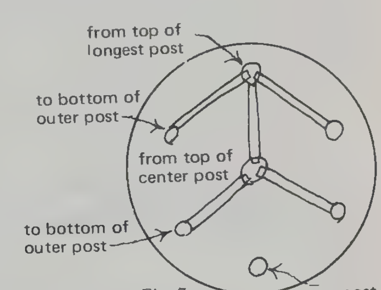
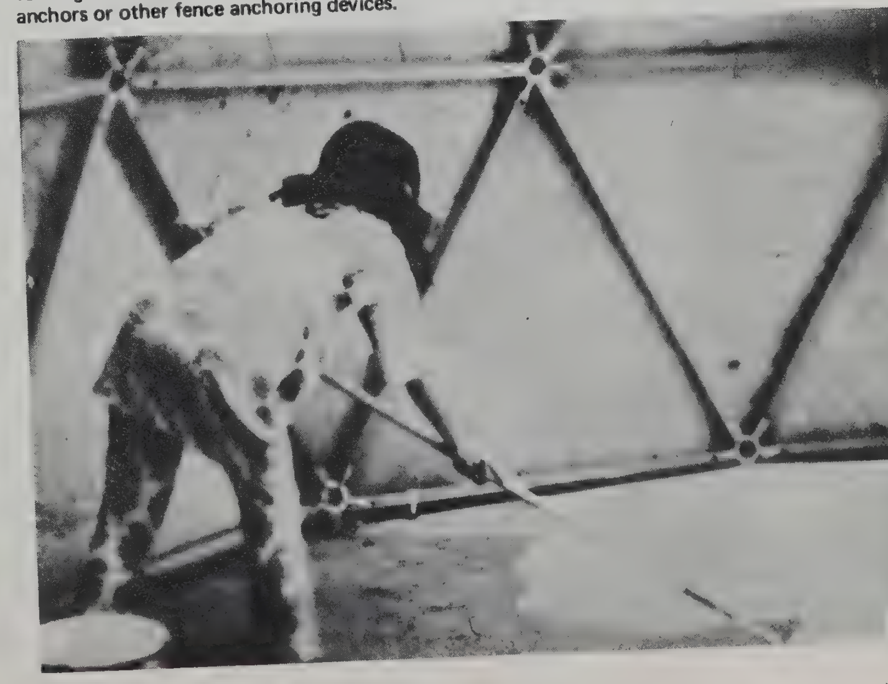


Fig. 7

The easiest way to do this is to install three diagonal braces from the top of the center post to the piers of three outer posts like a Mercedes Star. To combat torque, run two more braces from the top of the tallest outer post to the piers of the posts on either side. You have to do this or there will be trouble unless your dome is on very short posts. (Fig. 7) If high winds are expected, you will have to make some positive anchoring of the platform assembly, such as poured footings and iron brackets on the ends of the posts. **You could also use screw-in anchors or other fence anchoring devices.**



sealing

When you live in a dome, you gradually become aware that what you've built resembles a living organism. It is a mathematically derived membrane containing life inside. One unfortunate aspect of this symmetrical shell (for plywood domes especially) is that it breathes: expands and contracts. It loosens up in the sun, tightens when it's cold. Whatever it is that seals the domes at the seams must either be flexible and resilient, or extremely strong.

Think carefully about sealing your dome. If you don't do it properly at first, you'll end up spending four times as much energy (and money) in getting a watertight seal.

Because I was in too much of a hurry in sealing, it rained *inside* our dome in the first rainstorm. The three of us ended up huddled in a dry spot on the floor in the least wet sleeping bag. Later I remedied the leaks, but the hassle was frightful. Everything else in the dome can work beautifully, but if you have bad leaks, you'll probably be contemplating suicide.

Get the best advice obtainable, decide upon a method, or several methods, and make tests. Try to simulate the stresses that the dome will actually undergo in the tests. The best source of information on sealing joints we have found is the Harold A. Price Co., Inc., P. O. Box 1389, Richmond, CA 94802. Once you have a design, write them, giving specifics, and they'll tell you what type sealant would be best. I suggested to them that if they get enough inquiries they might mimeo a sheet on sealing domes. They said o.k.

We'll describe what we have learned.

Important to remember: windows and vents are the worst potential leak areas, as they break the dome membrane, and invite water in.

We have tried two methods of sealing joints: tapes and caulks. Tapes span the gap, gripping the membrane on either side; caulks fill the joint.

TAPE

1—Rigid: fiberglass tape or mat has been used with varying success by different dome builders. At this point I'm not sure as to its long-range sealing abilities. It's extremely strong, somewhat difficult to apply, and there is a danger in developing hair-line cracks due to dome movement. It probably works best in areas where temperature changes are not too great or frequent. You should consult with fiberglass companies as to these aspects:

a) flexibility: there are flexible resins. Are they weaker?
b) tape or mat? Tape is much more expensive but stronger than mat, and easier to apply.
c) ultra-violet resistance of the resin. Look into surfboard resin.
d) check into polypropylene cloth, supposed to be much more flexible than fiberglass, and it can be used with polyester resin. Write the National Fisherman (see bibliography) for current information.
e) pigment or paint. You'll have to use one or the other, as clear fiberglass deteriorates and darkens, getting a mottled appearance.

Bill Woods of Dyna Domes caulks seams with a mixture of Cabot-sil (thickening powder) and resin, using a rubber squeegee shaped like this,

available from fiberglass dealers. Then a 4" wide strip of fiberglass mat is applied over that with a 4" roller.

Note: the seam must be filled, and *it must be smooth* for subsequent application of tape or mat. Even small bumps will cause air pockets and trouble.

2—Flexible: what seems to be the best flexible tape available is Fab-Dek. It is reportedly used successfully by Pease domes in the east. It costs about 10¢ per ft., plus the adhesive. The company also makes other roofing materials which might be adaptable to dome seams, and it might be possible to save on the Fab-Dek tape by buying a large sheet of it (it comes in rolls) and cutting it into strips. See materials sections for address.

3—Pressure-sensitive tapes: this would be the answer: an easy-to-apply tape, no sticky adhesive needed, no need even to caulk. If it deteriorated after a few years, you'd just peel it off (unlike trying to remove non-functioning caulk, or tightly-adhered tape). Jay has built an aluminum sailboat, sealing seams with electrician's tape 3" wide. We are trying some tests on this tape, but don't know enough yet to recommend it. Jay says that paint will destroy it, so the dome should be painted before application.

It is absolutely necessary that the edges of the joint to be taped are dry, smooth, free of dust and little pieces of dirt or sawdust in the paint. The tape should be at least two inches wide and at least 6 mils thick. Vinyl electrical tape made to military standards is available in larger cities in any width you might need, at supply houses specializing in tapes for electrical things. The only economically practical tape available at this time is vinyl. Be sure that its specifications will allow it to live with your climate. "Shingle" it at intersections. After applying (it takes a person at each end of the strip), roll it down hard with a hard rubber roller. If your joint edges are too rough the tape will be cut by them. Do not stretch the tape as you apply it; and avoid making wrinkles. Black tape lasts longest. The hotter the day of installation, the better.

4—Airball: not actually a tape, but it works the same way. Bud Lindsay, a boatbuilder, told us about it. It's a liquid that is used in conjunction with canvas or muslin to seal boat decks. You put the liquid on, press the cloth over, paint on more liquid. The brand I saw was called Easy Deck; it is about $5 per gallon, and if it works, would be about the cheapest way to seal a dome. It's water soluble (until hard) so easy to work with. If you test it, let us know if it works.

CAULKS

Caulk spans the gap between dome seams. It must be flexible enough to allow for dome movement, yet not pull away from edges it is adhered to. If caulk is used in conjunction with paint, or tape, you must check the chemical properties of the caulk to make sure it is compatible. Also, a good caulk is not enough: you also need a properly designed joint, and good application technique.

From Dean Fleming of Libre

40 ft 4 phase [frequency] dome has been up 18 mos. Sealed 4 times with neoprene but can't stand the changes. New 22 ft 3 phase—up since last July—has not leaked a drop:

Permalume Plastics Corp.
5015 N. E. 78th St.
Vancouver, Washington 98665

First smeared M45 Mastic Caulk *on 2 x 4, then put down plywood, then sealed from the outside with caulk, then slopped BC chrome* elastomeric liquid-foil *generously on the seams laying muslin (diapers) strips down (about 3" wide), after paint had set a week I gave the whole dome a 2nd coat. This spring I'll add another & probably some color (enamel). The little dome is doing very well—the big's not! We used gaco, tar, neoprene enamel & finally permalume. Gaco does not adhere to raw wood—permalume soaks in beautifully—is saturated with aluminum pigment. As a painter I must say I was influenced by the nice thick way the foil laid on. Libre is still divided: Peter swears by Gaco, Tony hates permalume only a little less than Gaco, two Steves used alumination (tar & aluminum pigment) only to watch it decay within 2 months. I like permalume & my 22 ftr is now in the best shape at Libre. Caulk is $5.40 gal., spreads like junket—chrome is $4.80 gal. (in 55 gal. order) covers very well.*

Cement may be good—but hard work in all ways—especially curing in this country. (Water!) Plywood is good for ease of working and strong enough to stand on. Steve's celotex exterior is sagging. Wood maintenance is like a boat but less often. We need more time to really tell.

O.K.,
Dean

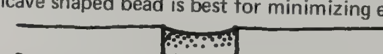
Joint design

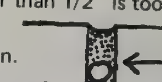
Expansion and contraction difficulties are minimized by designing joints that are wide and shallow. The depth of the sealant should never exceed one-half its width and preferably should be less than one-half the width.

Minimum width of joints: 1/16"

Maximum depth: 1/2" for joints greater than 1". Anything deeper than 1/2" is too slow to cure. A joint filler can be used to lessen depth of joint.

A concave shaped bead is best for minimizing expansion-contraction.





Caulk application

Caulk is difficult to apply to dome seams with a standard hand gun. The worst aspect of our plywood domes is the unevenness of the exterior seams. Since building the domes, we have learned of three things that we could have done to produce better seams:

1—You can get an air gun, for $30-40 that will run off a nitrogen tank. The caulk comes out under pressure and is forced into the seam. We'd have done this if we'd known, with a small nitrogen tank in a back pack or harness.

2—You can get special putty knives for seams. After the caulk is applied (with hand gun) you dip knife in soapy water and run along seam. *Note:* this only applies to moisture-curing caulks.

3—We had trouble with cartridges bursting in cold weather (caulk gets rigid). A closed cartridge type caulk gun, with metal cylinder that completely encloses tube might remedy this.

These instructions are for Vulkem. Other caulks may have different requirements.

Remove all moisture, dust, dirt, grease, etc. with brush or air blast. Use a joint filler, or piece of polyethylene so caulk does not stick to strut.

Method: start from the bottom of the joint. Push the caulk in, with pressure. Don't just lay it in. Force it against the sides of the joint. Press out any air bubbles. Use soapy water as a lubricant and a special caulk putty knife to smooth out the caulk. You can paint over the caulk in about 24 hours. It cures on down (from top to bottom of seam) at the rate of about 1/16" per day.

Estimating sealing requirements

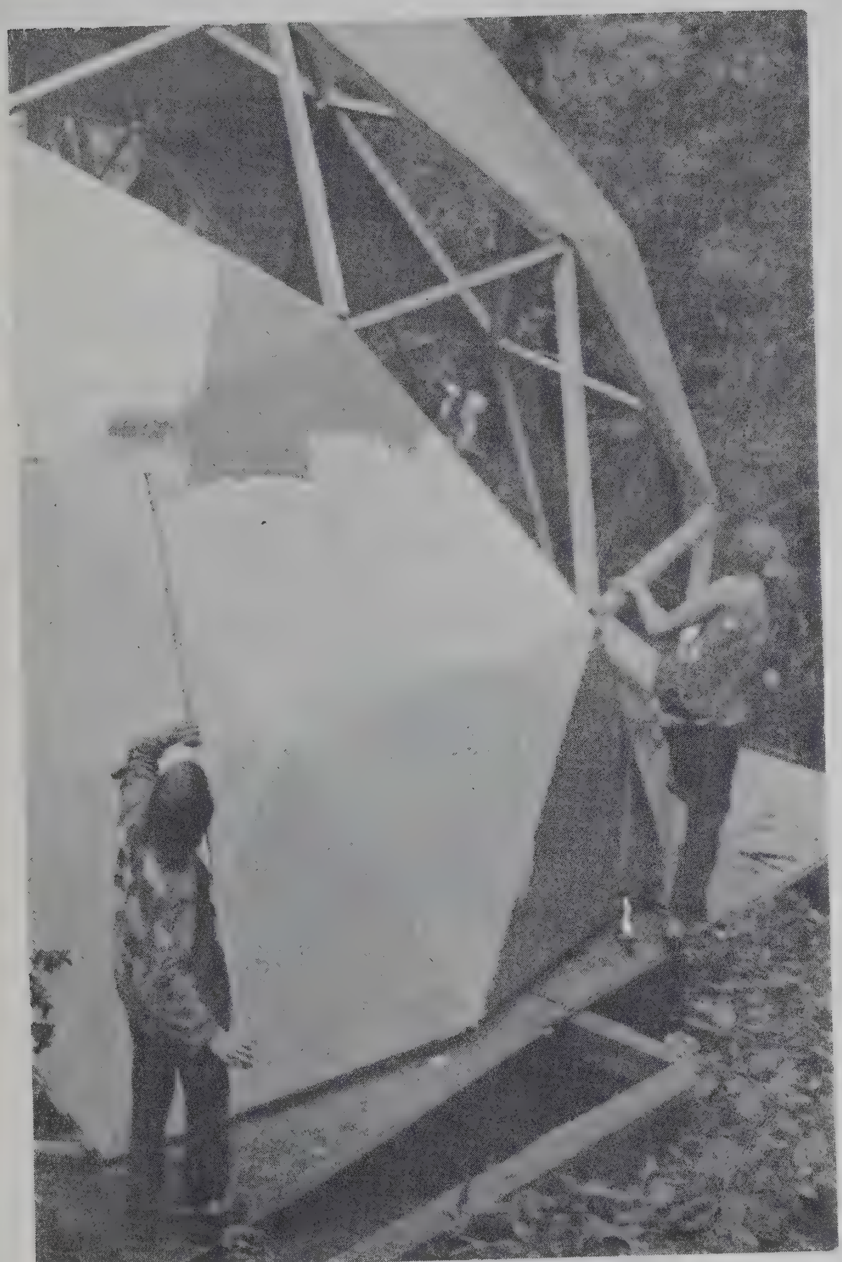
LINEAR FEET PER GALLON

DEPTH — INCHES \ WIDTH — INCHES	1/16	1/8	1/4	3/8	1/2	5/8	3/4	1
1/16	4928	2464	1232	821	616	493	411	307
1/8		1232	616	411	307	246	205	154
3/16			411	275	205	164	137	103
1/4			307	205	154	123	103	77
3/8				137	103	82	68	51
1/2	....	...			77	61	51	38

Knowing what we know now section: If it's a plywood dome, if you're going to live in it, I'd try a combination of Vulkem caulk and a compatible tape as double protection. However, you'll have to get the caulk on completely smoothly, with no bumps, or you'll have air pockets in tape.

Remember—the dome is all roof. Water runs over the entire surface. If you have window batts, or other things (vents, doors) that protrude beyond the surface membrane, do they make little catch-basins where water will collect? If they do, there'll be erosion, or rotting problems.

We have used Vulkem 230 one-part polyurethane caulk, about $1.90 per tube. It adheres to wood, concrete, metal and needs no primer (as does Thiokol). It cures when exposed to either air or moisture; you can add more new caulk on top of old; it does not have a solvent, and can therefore be used on vinyl without eating up the vinyl. It can be painted over (paint won't adhere to silicone caulk). It withstands temperatures of -30 to 160 and has a tensile strength of 130-160 psi. It is cheaper than silicon caulk, and seems to be just as good in this application. There is a five year warranty on defects and a guarantee that it will not become brittle and crack from expansion and contraction.



Most of what I've learned about caulks has been from Harold A. Price & Co., Inc. (see above). They are distributors of sealants, coatings, caulking compounds and tapes. They deal with all manufacturers, so don't have to push one company's product. Following is a reprint of portions of an article by Harold Price, describing properties of different sealants. Mr. Price told me recently that although polyurethane and silicon caulks were new when the article was written, both have proved extremely reliable.

Excellent sealants with true elastomeric properties are made from blends of synthetic rubbers, such as chlorsulfonated polyethylene (DuPont's Hypalon) and neoprene. These are single-component ready-mixed sealants which cure to a rubber gasket-like state within 60 to 120 days after application. As volatile solvents are used, shrinkage may amount to as much as 25%. Well designed joints sealed with this material will accommodate movement up to 25% of joint width. Resistance to weather is excellent and satisfactory service for periods as long as 15 to 20 years is expected. Price range is $14.00 to $18.00 per gallon.

Compounds formulated of acrylic resins are similar to the above in performance and price range. They have excellent adhesive properties but tend to absorb dirt and harden with age. At temperatures below 75° F. they must be heated before applying.

The two-part rubber base sealants compounded with Thiokol Corporation's polysulfide liquid polymer, reinforcing agents, resins and pigments are the most versatile of all true sealants. They possess superior physical properties of high adhesion, cohesion, elongation, weather resistance, and rapid cure that make them ideal for application in building construction. These properties can be varied, within limits, to meet special requirements for hardness, elongation, tensile strength, etc. Accurate control of mixing and application is required. Life expectancy is estimated at 20 years. Satisfactory seals are maintained with joint movement as high as 50% of joint width. Price range is $17.00 to $25.00 per gallon.

One-part rubber polysulfide compounds are a relatively new development. Physical properties, when cured, closely approximate those of the two-part compounds but cure time varies from 14 to 180 days, depending upon formulation and atmospheric conditions during the cure cycle. Price range is wide—$15.00 to $35.00 per gallon.

The newest sealing compound available to the building industry is based on silicone rubber. Used since 1940 in aircraft and missile applications, it is now available as a single component construction sealant. It cures to a flexible rubber in 24 to 48 hours upon contact with moisture in the air. Advantages include long service life (estimated 30 to 50 years); minimum shrinkage, unaffected by environment; and a wide selection of colors, including translucent. Present formulations produce a tougher and harder rubber than the polysulfide liquid polymer sealants used in building construction. Elongation is therefore not as good and bond stress is higher. Adhesion to glass and metal is better than to concrete substrates. Price range is $26.00 to $40.00 per gallon.

We are frequently asked to determine why sealants fail. Whenever adhesion is lost or the material splits apart, it has failed. The cause is frequently a combination of factors. Here are some of the principal reasons:

1. Improper joint design
   a) excessive movement: too narrow or too few joints
   b) inadequate bonding surface
   c) failure to provide balance between adhesive and cohesive factors when determining shape of the applied sealant
   d) three sided adhesion joints: sealant should adhere only to sides of the joint—never to the back.
   e) improper selection of backing material.
2. Loose or inadequate specifications
   a) improper sealant selection
   b) improper substitution
   c) accepted so-called equivalents which are not truly equal to specified sealant
3. Improper sealant formulation
   a) defective or old stock
   b) poor quality
   c) inexperience with uncommon metallic surfaces
   d) inadequate sealant manufacturing facilities
   e) lack of quality control
4. Improper application
   a) improper cleaning or surface contamination
   b) inexperienced or untrained applicators
   c) failure to use correct primer
   d) unauthorized substitution
   e) inattention to detail—sealant configuration—non-uniform installation or omission of backing material and/or bond breaker
   f) lack of inspection
   g) non-compatibility with associated building materials

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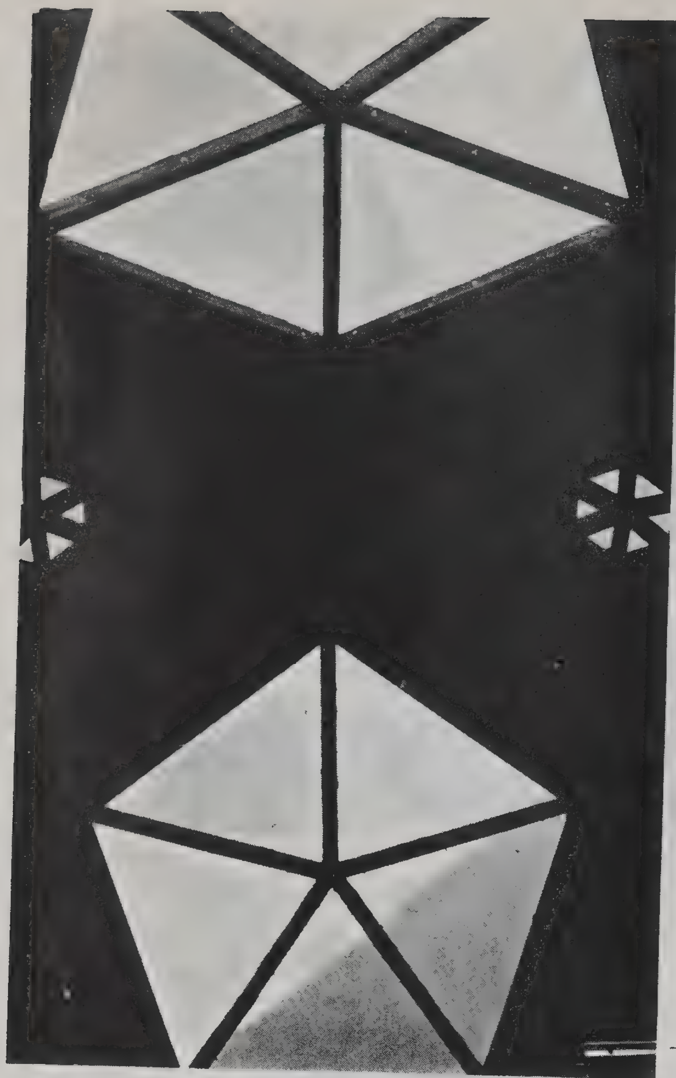
PAINT

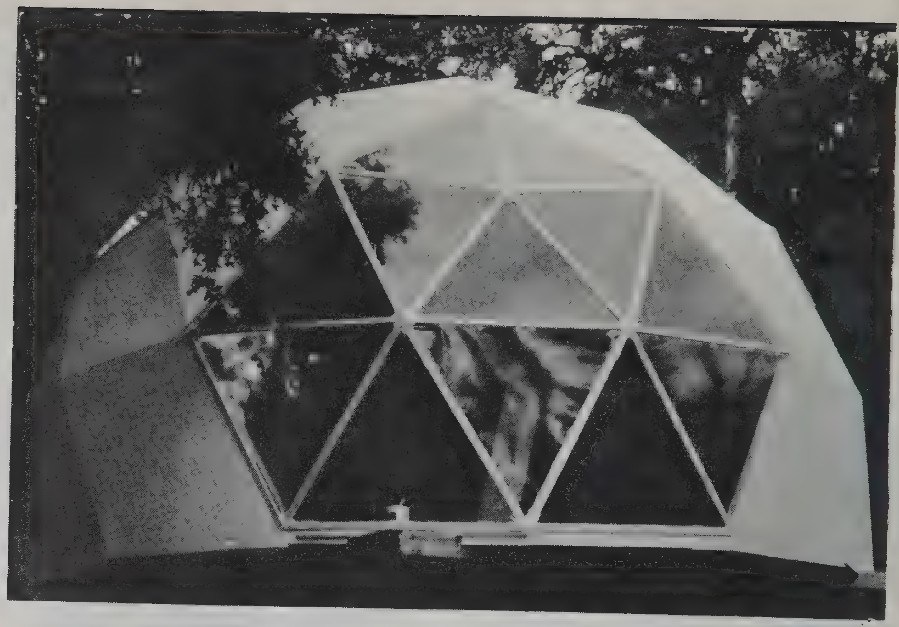
On our plywood domes we used De Voe paints, a marine grade primer, and Mirolac Enamel finish coat.

It's too early to judge the weatherability.

As with caulking, the paint you apply is extremely important, and you should do some research on the subject. Marine paints tend to be best, as they are directly concerned with preventing leakage. Some marine paints are flexible (See Materials section), but very expensive. Fiberglass sprayed (or hand layed-up matt) on the triangles before assembly is excellent weather-proofing. It must then be painted or a final coat with white pigment added. (You might be able to fabricate triangles of exterior plywood, then have them sprayed at a fiberglass place.) The plywood must be protected from the sun's rays and sealed from the winter rains (3/8" thick plywood will easily delaminate if not protected from the elements.

As with caulk, don't try to save money on paint. Cheap paint will end up costing more in the long run. Try to match colors of caulk or tape with the paint—white, preferably, as it reflects the sun's rays.





windows

There are many choices in pattern, construction, and materials with windows. A useful thing to remember is that a small amount of light coming in at the top will illuminate the dome surprisingly well, especially if the inside is white. If you want to minimize leakage problems, design and build windows very carefully.

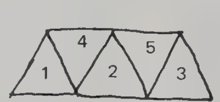
Vinyl windows: We used flexible 15 mil vinyl, with an ultra-violet stabilizer. It comes in 54" wide rolls, just wide enough for the large triangle. It's cheap—about 6¢/sq. ft. and easy to apply. It wouldn't do in snow country, and we regard it as a temporary measure. Here is how it is done:

Over the struts nail 3/8" strips—to bring the strut up to the same level as surrounding plywood.

We started out by cutting out the individual triangles (See Sun Dome for how to cut), 2-3 inches larger on each side than the actual triangle to be covered. Vinyl was then stapled on in this order with 1/4" rust proof staples. First panels 1,2,3 and then 4,5. This "shingles" seams for water run-off; always staple on "point up" triangles first.

It takes two people—one to stretch the plastic while the other staples. It works best to put a few staples in a vertex, then alternate back and forth between the two sides, stapling every 4" with the third edge done last.

On edges of triangles 1,2,3 the edges that were stapled to the strips were trimmed with a knife, cutting through the plastic against wood. On 4, 5 the plastic was held up and cut so none was against the next window.

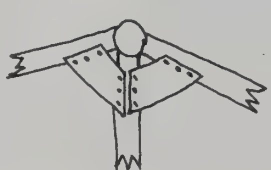


Next we ripped 1/2" x 2" batten strips on a table saw, painted them, and nailed them around all edges that had been stapled. The plastic was trimmed, and the outside edges of the batten were caulked with Vulkem sealant. Vulkem does not have a solvent in it, and does not eat away the plastic, as will many other sealants.

With later domes, we got into farther-out patterns, like equatorial arcs, diamond stars, and 12-triangle clear sections. We began to cut the windows in diamonds, and then discovered that to cover the long arcs, we could unroll a long section of the 54"-wide plastic, and staple it only on the edges where it met plywood.

In this case, battens are put along the perimeter, but are not necessary on the diagonal struts, which are not stapled.

One of the unsatisfactory details of using flexible plastic like this is that the battens stick up above the skin, and catch water. This is especially a problem for windows at the top of the dome. Also, the vinyl is not perfectly clear, has minor wave distortions, and we're not sure how long it will last. An important thing to remember is that where there are large window sections, the dome is much weaker, without plywood for structural strength. You may want to work out a detail for compensation here, such as this:



—*5 mil Mylar* was used on a large hillside dome in L.A., according to architect Bernard Judge lasted for five years, then became yellow and brittle and had to be replaced.

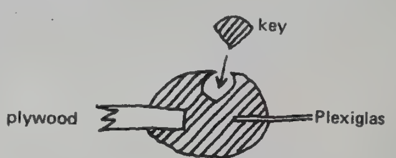
—*polyethylene* seems unsatisfactory, won't hold up for 6 months in sunlight.

—*Glass* is expensive, but still the clearest window material. Dangerous when used overhead if not safety glass.

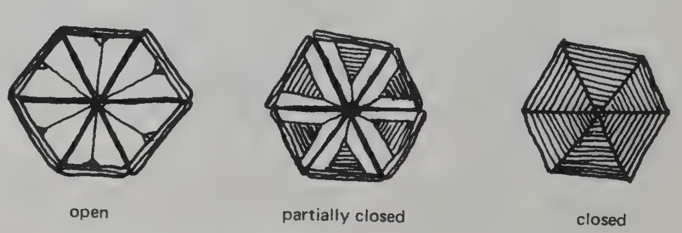
—*plexiglass* is expensive, but a good solution especially if you don't have a great deal of window space. The plexiglass skylights (see Materials Section) may be a good solution. Plexiglas may actually work out to be cheaper than professionally cut glass triangles.

We have also tried some Plexiglas with "lock and key" rubber extrusion. With this, the window is put inside the plywood. Installation is relatively simple and leakproof.

The rubber key is slipped into the slot with a special tool, which tightens the rubber on both plywood and Plexiglas.



EXPO Dome has shades that pull in to center of hexagons:



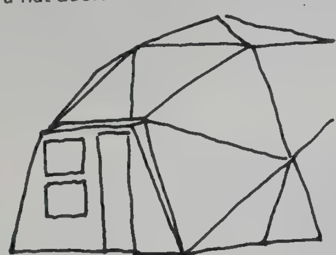
doors

There are two basic problems with dome doors, windows and vents:

1) Since the dome is all roof, water pours over the entire surface when it rains. Openings invite leaks.
2) Tools, materials and principles for door-window-vent installation are mostly applicable to rectangular, 90°-to-earth installation. When you depart from this, there are many design problems to be considered.

When you start cutting openings in the dome shell, you suddenly realize how efficient the rectangular building is with respect to waterproofing: the roof, which takes most of the rainfall, is covered with tar, or roofing paper—which is leakproof—and water merely runs down and off. You don't even have to be very careful in application of roofing material. But with a dome, a pinhole in the surface brings moisture inside.

Rectangular door: practical, and ugly. The easiest thing to do is to frame door opening outward and put in a flat door.



Trap door: If the dome is on a hillside, this is a solution, and one which we have used with six domes. The advantage is that you don't have to cut into the shell. Disadvantages are

—it uses up floor space (when open);
—it tends to be dangerous, unless you build handrails and some kind of guard around hole to stop people from falling when door is open, and the door can fall on you when you're descending the stairs. We Skil-sawed section out of the 1 1/8" plywood floor, then made doors out of the sawed-out section. Section was cut in half, so door wouldn't be too heavy to lift, hinged, and handles attached for opening and closing.

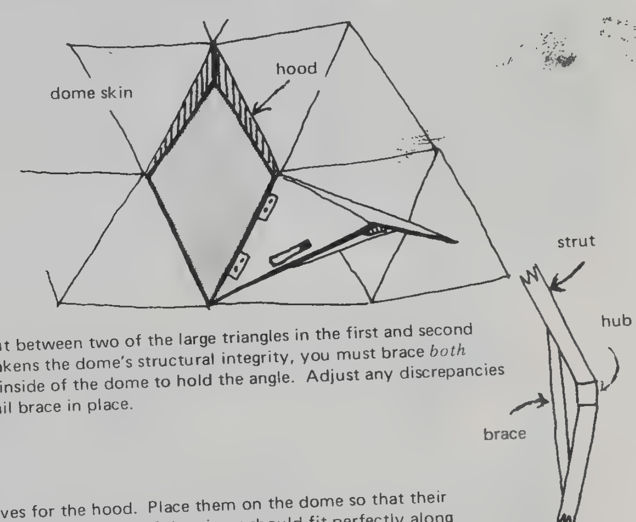
My door is 3' x 5'; I can fit a 4' x 8' sheet of plywood through this door. If I did it again, I'd try to make it of a lightweight material—like a sandwich fiberglass panel—so it wouldn't be so heavy to lift.

Triangle door: merely hinge one of the triangles—work out a detail for shedding water. This is the simplest door, and causes one to stoop each time the dome is entered.

When his new tea-room and garden were completed at Sakai, he [Rikyu, a famous Japanese tea-master] invited a few of his friends to a tea ceremony for the house-warming. Knowing the greatness of Rikyu, the guests naturally expected to find some ingenious design for his garden which would make the best use of the sea, the house being on the slope of a hill. But when they arrived, they were amazed to find that a number of large evergreen trees had been planted on the side of the garden, evidently to obstruct the view of the sea. They were at a loss to understand the meaning of this. Later when the time came for the guests to enter the tea room, they proceeded one-by-one over the stepping stones in the garden to the stone water basin to rinse their mouths and wash their hands, a gesture of symbolic cleansings, physically and mentally, before entering the tea-room. Then it was found that when a guest stooped to scoop out a dipperful of water, from the water basin, only in that humble posture was he suddenly able to get a glimpse of the shimmering sea in the distance by way of an opening in the trees, thus making him realize the relationship between the dipperful of water in his hand and the great ocean beyond, and also enabling him to recognize his own position in the universe; he was thus brought into a correct relationship with the infinite. . . .

From Japanese House & Garden *by Dr. Jiro Harada*

Diamond door: Wayne Cartwright designed and built a unique diamond door. It's hard to explain, and some details still have to be worked out, but this will get you started:



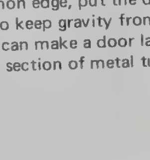
Remove a horizontal strut between two of the large triangles in the first and second course. Because this weakens the dome's structural integrity, you must brace *both sides* of the door on the inside of the dome to hold the angle. Adjust any discrepancies with a plane, and glue-nail brace in place.

Use two scrap triangle halves for the hood. Place them on the dome so that their right angles are away from the dome. One of the pieces should fit perfectly along its strut, the other an inch or two too large. Also, one piece will be too large at the right angle. Mark accordingly, and with an angle marker measure the angle beneath the peak.

Set the saw at the bevel and rip a piece to fit inside along the peak.

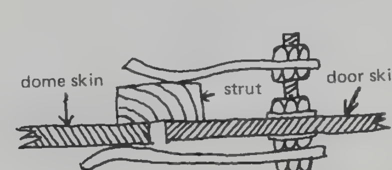
Next, make two 1 x 2 pieces for the door to rest against. Set them back 1/2" from plywood edge.

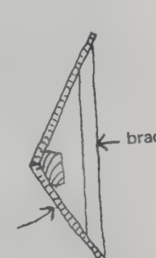
Then nail everything together and onto the dome.



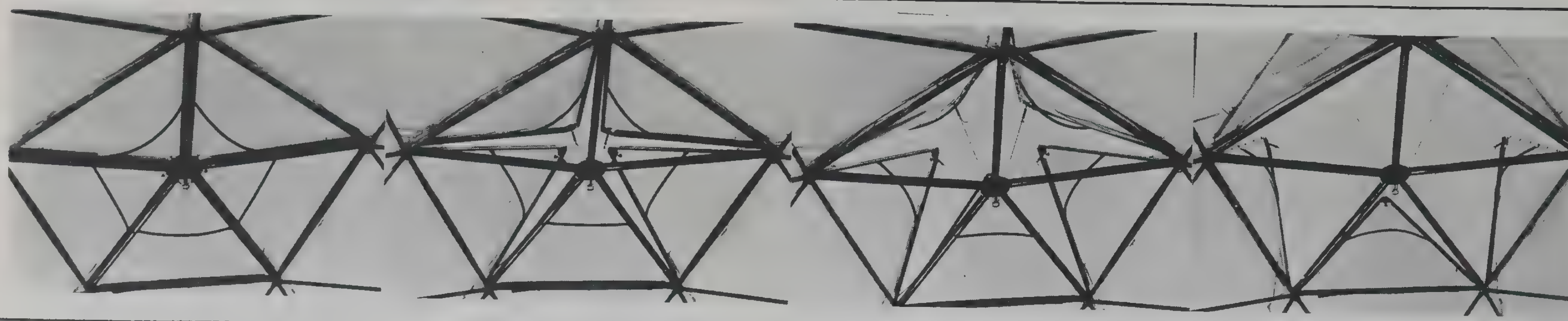
To make the door, hold two full triangles (or four scrap halves) against door opening and mark from inside. In cutting allow for 1/4" gap between dome and door plywood. After trimming, place the triangles back into the doorway and measure the angle for the piece that connects triangles along their common edge. A brace connects the two tips of the door. Mark for this the same way as the brace inside dome.

Nail the two triangles together along common edge, put the door in the doorway, nail cross brace on, put on hinges, and add a spring to keep gravity from crushing the door against the side of the dome when it's open. You can make a door latch as shown. To stop the rod from wearing a hole in the plywood, add a section of metal tube to where rod passes through plywood.





And if that's not clear, write Wayne.

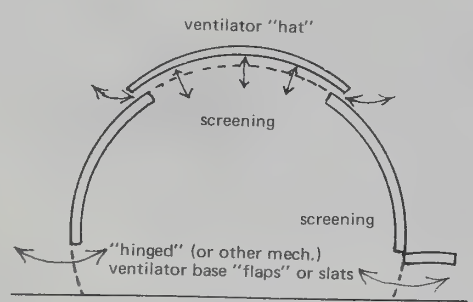


vents

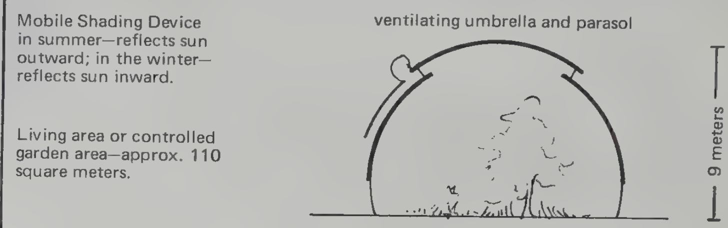
A partial sphere seems ideal for a natural cooling and circulation system.

Extract from Item "M", Boston Blue Print Data Archive, R. B. Fuller:

Be sure to design your building with *large* ventilating and reflecting areas *both* top and bottom with screens, etc.

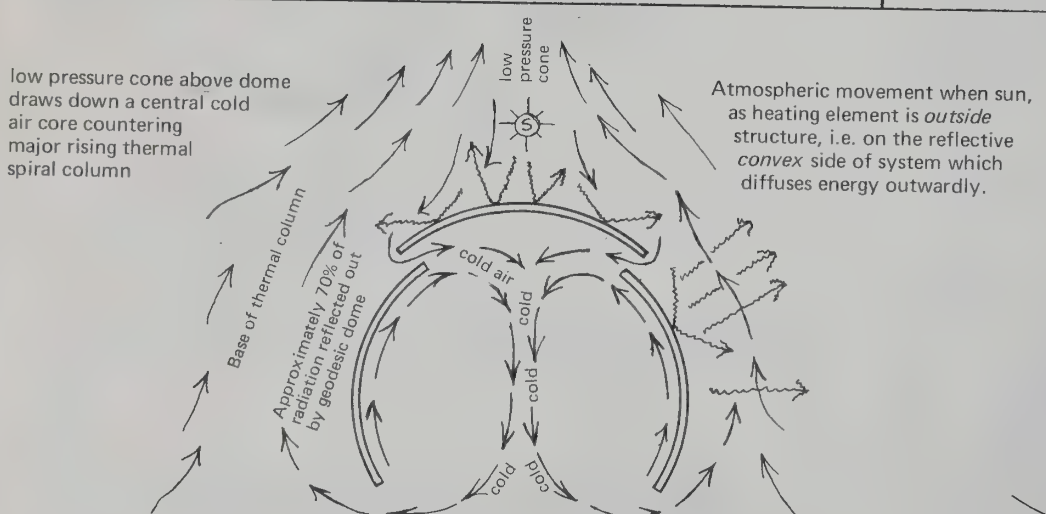


If you use a six-meter radius and a 5/8 sphere, your structure will look about as below—and, as you have learned, the seemingly empty space is full of *invisible energy operations* in your favor. Trees may also live inside, to mutual advantage of man and tree.

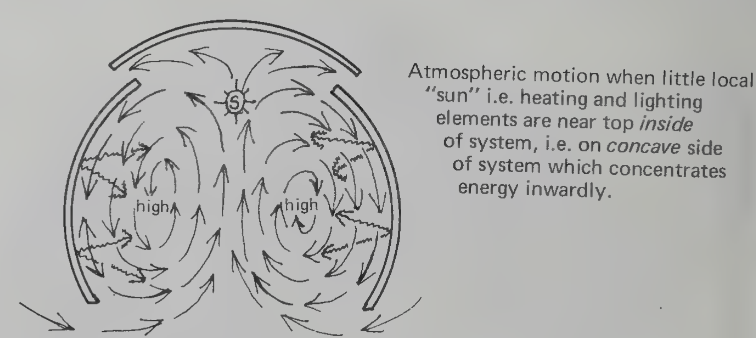


This space should be treated as a controllable outdoor garden, with the concept of a *"house" as a "fortress"* completely dismissed.

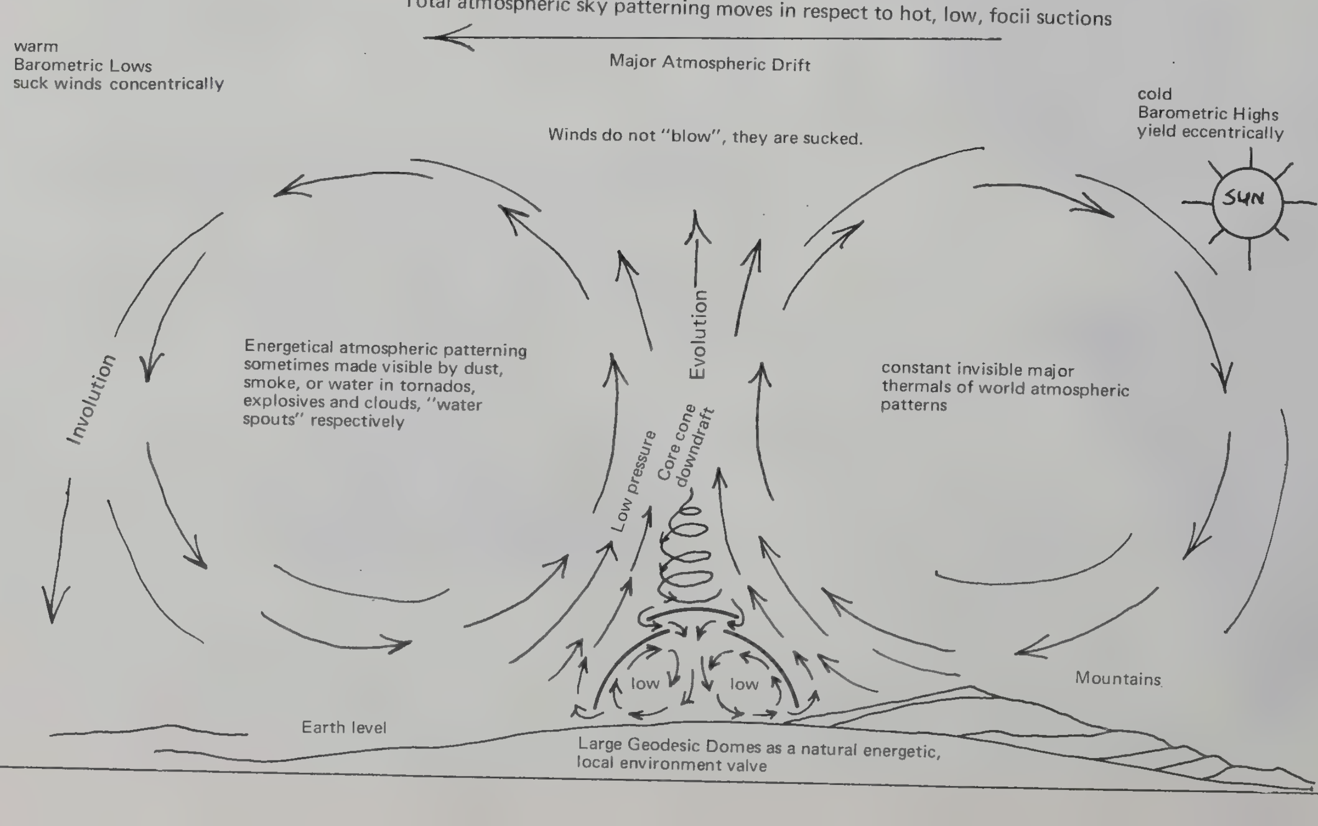
Think of the structure as the masts and spars of a sailing ship were thought of, i.e., as a mobile system of overhead "vantage" (as with shipyard "cranes") for mounting any kind of local "circuses" of atmospheric and energetic events. Send skins aloft like sails on a ship.



Interior motion is an involuting torus (doughnut shape)

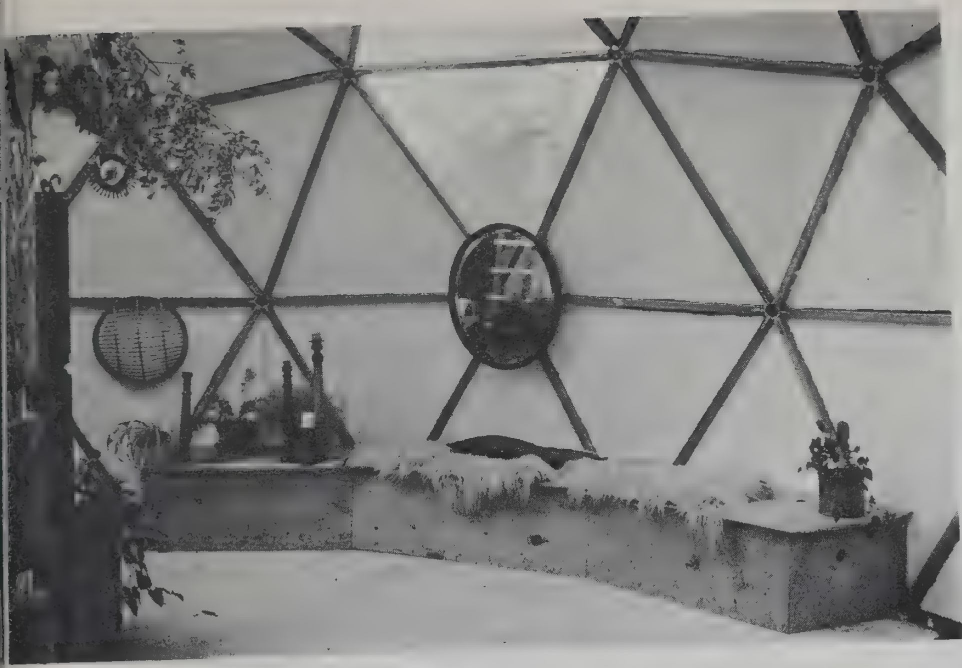


Interior motion is an evoluting torus (doughnut shape)



The scheme is to induce thermo evolutions and involutions to take a natural reciprocal course *through* geodesic environments, thus employing the *vacuum* drags of the patterning and its obstructions to pull the interior airs over preferred patterns. This is accomplished through convex-concave *shapes* and dimensions of openings and reflectors.

interiors

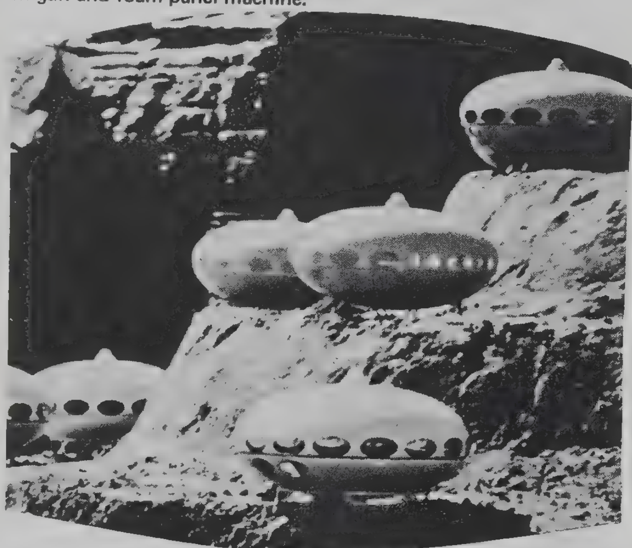


PLASTIC FOAM

As you may know, polyurethane foam is one of the most exciting new building materials. Since it can be shot from a gun, the builder is not limited to putting together pre-cut components. This allows great fluidity in form, as evidenced by early work done by Douglas Deeds (San Diego) and Felix Drury (Yale).

Foam is the best insulating material known, and with fiberglass or other membrane as sandwich covering, can be structural.

Bill Woods of Dyna Domes has done some important one-man foam experimentation, has built several 100% foam buildings using a specially designed foam gun and foam panel machine.



The Futuro house, designed by Finns, is the first successful looking foam-fiberglass house to be offered for sale in the U. S.

My intuition tells me that plastics are the building materials of the future. Trees are being cut down at an alarming rate and there is obviously not enough wood to take care of the housing needs of any but the wealthiest citizens on Earth. Early World Game reports indicate that at the present rate, the use of metals in housing will be insufficient, and " . . . metaphysically-engendered materials such as plastics will have to be developed if we are to solve mankind's housing needs."

There is a great need for someone to make a thorough study of the prospective uses of plastics in housing. Those of us now arguing pro and con don't really know what we're talking about. Which plastics are made of soy beans, which plastics can only be made from non-renewable resources like oil? Are they actually non-disintegratable? (Polyurethane foam disintegrates 1/16" per year if exposed to sunlight.) What will be the effect on planet oxygen supply if we keep cutting down trees at the present rate? (You *know* that very little timber land is being replanted) How much pollution is released into the atmosphere as a result of the plastics manufacturing process? With a plastic-insulated house, three times as efficient as normal, how much heating fuel do you save and how much less air pollution do you cause over a 20-year period? Can plastics be recycled and reused? And etc. Help us answer these questions, not with opinions, but with comprehensive facts. In the next issue of this book we hope to compile answers to these and similar questions so that dome builders will be able to think in comprehensive terms of the materials they use.

Following are articles prepared by two men who have worked with polyurethane foam for some time: designer Douglas Deeds, and experimental builder Ron Swenson.

Foamed Plastic for Shelters

Douglas Deeds

The introduction of foamed plastics into the technical melting pot has generated a great deal of interest in foams as a possible solution to housing problems. Having had a reasonable amount of experience with these materials, I feel that they may hold the key to future housing or shelter construction breakthroughs.

Basically, foamed plastic is a thermoplastic or thermoset plastic resin into which, chemically or thermally, bubbles or cells have been introduced. It's much the same as a loaf of bread rising due to the action of heat and yeast. The curing of the foam creates a rigid cellular substance. The thermoplastic foams may be formed with the application of heat; this is not so for the thermoset foams.

One of the most important aspects of foam technology is the totally organic nature of the material. This would also apply to some of the reinforced plastic materials as well. For the first time in the history of mass produced materials we have components capable of being made into any conceivable shape and form. The use of the material has not been limited to some pre-formed industry-issue shape such as an "I" beam or four by eight sheet. No longer are we given limits based on what is convenient for the machine that makes the materials with which we build.

This, of course, leads to an aesthetic dilemma. We have developed a taste and fashion sense around the straight line. Suddenly, all stops have been removed. This is sort of scary for those trained in the dogma of triangle and straight edge. It is also uncomfortable for consumers who have been raised on the gruel of equating straight lines with man's dominance over materials and nature. Now we have materials that, at least in form and configuration, can be in harmony with nature.

1. What advantages does foam offer in the construction of a shelter?

The use of foamed plastics for shelters, as stated above, completely frees the form and shape of the end product. This is much more important in its ramifications than simply allowing the constructor free reign in exploring his whims. The structure can be completely site-adjustable; it does not require the leveling of the terrain to make it convenient for someone to pour a concrete slab. The structure can be in complete harmony with the site—not an eyesore on the landscape or, worse, a cause for scarring the landscape.

Foams and other reinforcing materials (such as fiberglass reinforced plastic) allow total fabrication of the shelter on the job site. The key concept here is that the factory is, in essence, brought to the job in the form of a small mobile unit capable of applying foam and reinforced plastic. The molecules jumping around in the barrels still haven't been told what shape to be. Also, they are not in pre-shaped sheets, tubes, etc., which are bulky to transport. Foamed plastic expands to many times its liquid bulk upon application, providing economy of material. Two gallons of material thrown together suddenly expand to become several cubic feet of rigid material. The equipment needed to erect the basic shell of such a structure can easily be contained in the back of a small truck. Because there are only, at most, two or three materials used (all transported in drums or condensed state) there isn't the bulk transportation problem encountered with conventional building methods.

Mistakes are mendable with the use of foam. The error can be carved away and new foam "grown" in its place. Small details can also be introduced by carving into the cured foam. As an added benefit, cured foam proves to be a moisture and vermin resistant material.

The materials involved in constructing a foam structure are costly, on a per pound basis, compared to conventional materials. However, other factors need to be considered to give an accurate overall cost performance picture. The speed and ease with which a foam structure can be erected greatly reduces raw labor costs. Also, in dealing with only one basic set of trades people, the problems involved in multi-contractor construction are minimized. The insulation qualities of foamed plastics are widely known to be far superior to any other materials available. The reductions of basic heating/cooling unit cost plus long term heating/cooling cost savings must be considered as a distinct advantage.

The creation of the raw materials, from which a synthetic house is created, cause a resource depletion. However, if a synthetic shelter performs more efficiently, and does not generate further resource depletions, it is surely a step in the right direction. Conventional building techniques drain resources from the outset and their sieve-like inefficiency demands further consumption in the form of great quantities of gas and oil to heat and cool them, to say nothing of the excess pollution caused by the inefficient transport of large, bulky materials to the job site. These factors are, obviously, reduced by the low bulk, site-adjustability, insulation quality of foam structures.

It is no longer practical, economically or ecologically, to chop down trees, saw them up into 2 x 4's and reassemble them in the form of houses. This simply will not meet the needs of the future for sheltering the earth's exploding population.

2. What are the disadvantages of foams for shelter construction?

One of the prime deterrents to the widespread use of foams for shelter building is the relatively high cost and complexity of the application equipment needed to gain the maximum benefits from foam's properties. A $5000 investment is not within the reach of the average experimental building enthusiast. Also, there is a good deal of skill required to apply the material properly and keep

continued

the spray equipment functioning. It should be noted that this cost and complexity is infinitely less than that required for any of the low cost housing schemes that are currently being proposed as solutions to the mass housing problem. These foam techniques present fewer limiting factors than the industrial approach. Mass production may have worked in the auto and trailer industries but it won't solve the needs of the shelter shortage. It's still stick building technique, no matter how automated.

At present, sprayed and poured foams, uncontained by molds, have a rather pebbly surface texture which might be unsatisfactory from a conventional aesthetic point of view.

The foams used to build most structures have very little skin strength and, thus, a shelter could be picked apart with the fingers. Ultra-violet light will degrade the surface of exposed foam, making it soft and crumbly. Both of these disadvantages could be overcome by coating the foam with reinforced plastic or other types of permanent skinning material.

Hazardous, toxic fumes that are given off by foams, when they are sprayed or poured, are a problem that must be realized. With proper breathing apparatus this is not a great danger, but, extreme care should be taken when working with any of these materials. Yes, this might be considered air pollution. However, to expand my earlier thesis, isn't it better to have a small amount of pollution to create something that is a thermally efficient shelter, thus eliminating the need to chop down trees or diminish resources and burn these products to create warmth? A little seive in the woods is very nice. But, eventually you will have to decimate the very woods you came to enjoy just to keep warm.

Another disadvantage with foam construction, though not inherent in the material, is the resistance that building codes put forth. This is, obviously, a problem that has many interrelated causes and effects much too tangled to delve into here. Suffice to say, that as long as the power structure in this country dictates the building codes and requirements, on a non-performance basis, there is little hope of new building technologies emerging on a wide scale.

3. What are some of the construction techniques available for foam shelters?

There have been a number of foam structures erected, during the past couple of years, using the inflated technique. Basically, one simply inflates a large balloon-like form with air and sprays urethane foam over it. The foam rigidifies, the air pressure is removed and a structurally sound building remains. The cutting of window and door apertures creates a "house," and some of these structures have been quite large. However, I find that the inflated structures have been limited in form and just scratched the surface of what might be achieved.

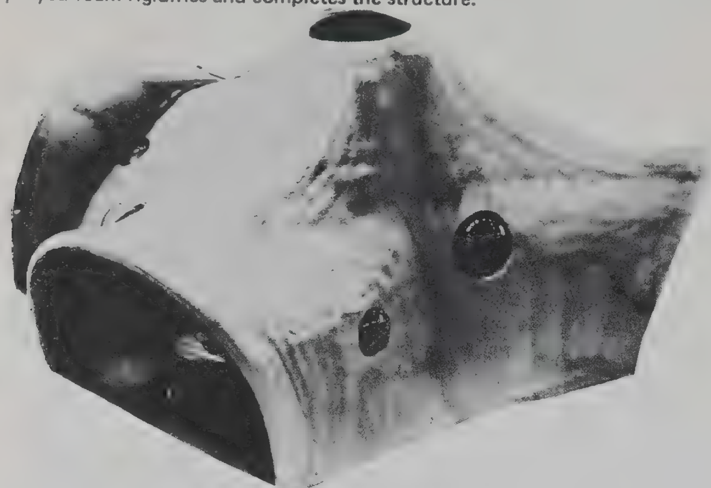
A method of construction which I used for the fabrication of a foam interior, in the Museum of Contemporary Crafts in New York, proved successful. Using spray equipment, the urethane foam was sprayed and "grown" on the floor surface and gradually built up to form the shape desired. The furniture and cabinetry were "grown" into the interior in this manner. The accuracy with which designs are formed, using this process, depends a great deal upon the spray gun operator. I was fortunate to work with an exceedingly adept gun operator on this project. There is virtually no limit to what could be done using this technique. However, it is somewhat wasteful of foam and time consuming.

Last September, I was privileged to design and construct an exhibit structure at the Smithsonian Institution in Washington, D.C. For this structure, I used a proprietary technique—stretchable fabric spread over tubular plastic arches. This formed the matrix over which the urethane foam was sprayed. There is great freedom of form possible with this method and it is very easy and inexpensive to construct such a matrix. The fabric surface makes the spray application of foam very simple and minimizes the labor involved.

This article was prepared by designer Douglas Deeds, 1706 W. Arbor Drive, San Diego, Calif. 92103. The first aesthetically pleasing use of foam I saw was the grotto he created in a New York office building in early 1969.

PLASTIC FOAM *continued*

With this process, it would be possible to ship the supporting tubular arches, rolled in sufficient fabric, to the job site. The arches could then be erected, the fabric stretched over them and the entire matrix sprayed with foam. The sprayed foam rigidifies and completes the structure.



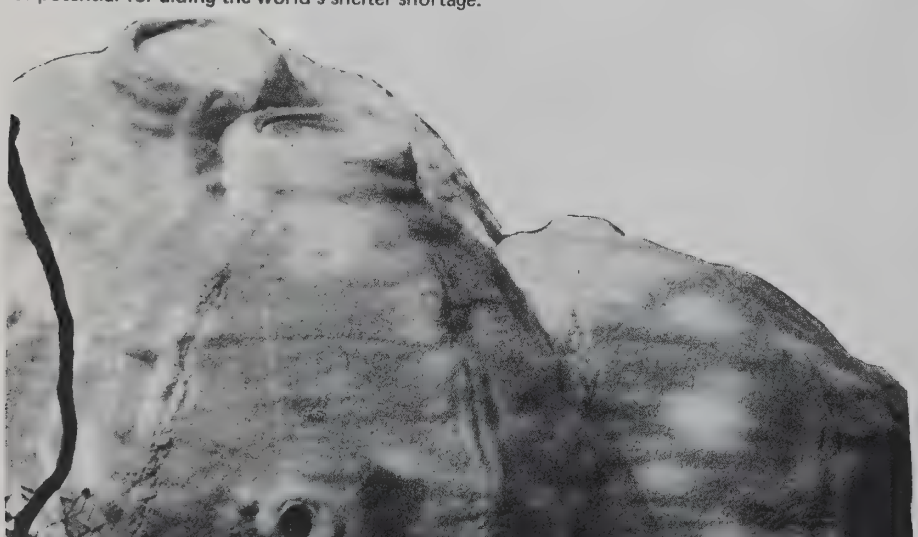
In these methods described, reference is made only to the use of foam. I feel that, to achieve a truly lasting and permanent structure, it is necessary, at least for the present, to skin the foam with some sort of coating. There are high density foams available for such purposes, as well as vinyl and rubber coatings. However, fiberglass reinforced plastic seems to offer certain advantages. The addition of tensile skins to both sides of a foam core yields an extremely rigid, lightweight, load bearing structure. To achieve the same load carrying ability, with foam alone, would require a much greater thickness of foam. The point of diminishing return is reached quite soon, at which time it is better to cease adding thickness and add thin skins.

Another construction method, which might prove feasible, is the use of thermoplastic foams. The sheets of foam are heated and formed over a simple jig (bent steel rod or tree limbs, a mound of dirt). When the foam is cooled, it becomes rigid again. Fiberglass reinforced plastic is applied to the outside of the foam and the jig removed. The interior is glassed and the structure stands as a complete shell. A similar method is currently being used on a wide scale for the construction of boats, some of which are quite large.

There is also the possibility of constructing a matrix of steel rod and wire mesh, over which foam could be applied. Then skinning the whole sandwich with FRP. The advantage that this might offer is a means of complying with the building codes. If the steel structure were self supporting and demonstrably load bearing, it might be possible to get approval on it. The foam is insulation and the glass roofing and interior coating.

At the present time, there are firms in the country who are experimenting with molding large foam building modules, using self-skinning foam. They hope to be able to produce a high volume of low cost housing. These modules may prove feasible for this need. Obviously, the costs of capitalizing such an operation, and the research necessary, put it beyond the reach of the one-of-a-kind, single family dwelling market. However, as urban crowding continues, the one-of-a-kind market will logically dwindle and the mass produced dwelling will find an ever broadening market.

As for the future of foam, it rests mainly with the expansion of existing trends in the materials development. We are sure to see self-skinning foams that will not require the use of exotic molds. Resistance to ultra-violet light degradations will be improved. Greater control of the surface finish will be possible, and certainly, simplified techniques of foam construction, without exotic equipment. It may even be possible to pre-program the molecules of the raw components so that the foam itself will know what shape and variety of densities to form without any outside help. One thing is certain: these new organic materials offer the broadest spectrum of potential for aiding the world's shelter shortage.



New discoveries in chemistry have led to the production of powdered and liquid materials which when suitably treated with certain activating agents expand to great size, and then catalyze and become rigid. We are rapidly gaining necessary knowledge of the molecular structure of these chemicals, together with the necessary techniques that will lead to production of materials which will have a specific program of behaviour built into them, while still in the submicroscopic stage. Accordingly it will be possible to take minute quantities of powder and make them expand into predetermined shapes such as spheres, tubes, toruses . . . double walls are windowed in new ways containing chemicals to heat, cool, clean, ceiling patterns created like crystals, floors formed like corals, surfaces structurally ornamented with visible stress patterns that leap weightlessly above us. . . .

Organics
William Katavolos

Parsons School of Design
New York, N. Y.

The Use of Polyurethane Foam in Construction
Ron Swenson

Polyurethane foam is one of the most exciting new materials available to designers and builders of housing today. All of us have become familiar with foam rubber in furniture—this is actually the flexible form of polyurethane foam in most instances. In addition, though, urethane can also be formulated to create a rigid cellular structure which has fantastic insulation characteristics and can be molded or sprayed to take on virtually any shape. The cost of urethane in liquid form is about 30¢-50¢/lb, depending upon quality and fire-retardant additives, but when the two oily substances are mixed, a catalyst causes the foam to rise up to thirty times its liquid volume. The cost then becomes roughly 10¢/bd. ft. (a board-foot is 1' x 1' x 1" thick) which is a very economical price in the proper application. Of course, this is only the material cost—labor costs depend upon the complexity of the job and upon who is doing the work.

TECHNIQUES

There are three basic techniques for the application of polyurethane foam: pouring, frothing, and spraying.

The *spray-up* technique is much like spray-painting. A machine pumps the two liquid chemical components into a heated hose, and the operator operates a gun which mixes and sprays the material in a fan-pattern. Foam can be applied to walls and roofs for insulation, or it can be sprayed on membranes to provide both structural rigidity and insulation. This technique was successfully demonstrated by Prof. Felix Drury, School of Architecture, Yale University, when he and a class of students sprayed urethane on several large inflated bags. The results can be seen at the Yale golf course or in any of a number of design magazines or in June 1969 Esquire (which shows a number of other plastic houses as well). Other membranes possible are stretched fabrics, or mesh over wooden, steel or plastic electrical conduit (PVC pipe) frames.

The most common application of *poured* urethane is for sandwich panels created by pouring foam in between two flat sheets a few inches apart. These sheets may be plywood, fiberglas or aluminum. The result is a structural panel without the customary 2X4 studs in between. Also, this foam may be cast or poured like concrete.

Frothing of urethane is similar to pouring, but the material is mixed in a chamber and has already risen 30% when it comes out of the hose.

BIODEGRADING

Many people are justifiably concerned about what happens to plastic when it becomes garbage. Of course the first question should be: how can we re-use plastics once a given piece of it is no longer desirable? Well, thermoplastics can be melted down economically, but urethane is a thermosetting plastic, not a thermoplastic which is molten and cools into a shape in a mold.

The answer is that urethane decomposes in the ultra-violet rays of the sun. This means that an exposed surface must be protected with any opaque paint or a fine orange dust will form on the surface and eventually wear it down. Another possibility is to use scraps of rigid urethane as a filler or aggregate in other materials when it no longer is needed in a particular application.

SAFETY

No one would think of handling molten steel during the fabrication process, or working in concrete with bare feet. Urethane should be treated with the same respect, and caution taken, even though it is not necessarily required all the time. Polyurethane contains tolylene di-isocyanate, which is a highly toxic substance that can irritate skin or cause congestion in the lungs if inhaled. All manufacturers supply safety information which should be read carefully, and where air supply equipment is needed, the added expense is cheap in comparison to the cost of temporarily or permanently impaired health. Generally, goggles should be used to protect the eyes, and when doing work indoors, fresh air supply equipment is a must, as well as complete covering of skin. For outdoor applications, spectators should not get down-wind of the spray, and if there is not a gentle breeze, it is probably desirable for the applicator to use a fresh-air supply or at least a respirator. Some people seem to have an immunity to the material, others can't stand the stuff, so a division of labor may be the solution in some cases.

SOURCES OF INFORMATION

The best source of information on urethane foam is Mobay Chemical Company, Pittsburgh, Pa. 15205. They have a series of articles called "Urethane in Building" which are available by writing. They also have a number of pamphlets, notably "The Use of Rigid Urethane Foam as a Structural Insulant".

Modern Plastics Magazine, P.O. Box 430, Hightstown, N.J. 08520. $12/yr. A monthly magazine with latest plastic news, and a yearly "Modern Plastics Encyclopedia", a bargain, and the best current plastic information source available.

"They Built Their Home With Foam" by Lora Lee Watson, Home and Recreation Section, The Minneapolis Tribune, Sunday, Nov. 2, 1969, describes an interesting approach to urethane building, the "Ensculptic House". The house is being built by Ensculptic, Inc., a corporation formed by James L. Littlejohn, Winslow Wedin and John Hartwell. Wedin is a professor of architecture at Auburn (Ala.) University and the house is in Minnetrista, Minn. The basic shell is foam sprayed over burlap, which was draped tentwise from a tall central mast, over nylon cables. The foam is then covered with an organic-colored fiberglas surface.

Plastics in Building, by Irving Skeist ($18 from Van Nostrand-Reinhold, 450 East 33rd St., NY, NY 10001) is also a valuable source of information.

This article was prepared by Ron Swenson, 777 North First Street, San Jose, Calif 95112. He is president of SBT, Inc., a company which is prototyping an all-plastic house using thermoplastic and fiberglas skins over rigid urethane insulation (sandwich panels). It consists of modules which can be arranged in a variety of ways to produce a home of 500 square feet up to 2000 or 3000 square feet. He also has a spray application organization, Polyurethane Applicators, which does urethane roofing, insulation and experimental buildings.

ferro-cement

In the pelican pond at the Amsterdam zoo is a ferro cement sloop built in 1887—still floating.

This low-cost, easy-to-work-with material has recently come into widespread use with boat builders in Canada and U.S. It is composed of basically the same ingredients as reinforced concrete, but is mixed in different proportions. Whereas reinforced concrete is generally 4″ thick or more, with relatively small amounts of steel, ferro cement is a very thin (1/2-3/4″) membrane with a good deal of steel reinforcing. A rich mixture of cement and sand, applied over a steel mesh framework, with no forms: this characteristic makes ferro cement immediately desirable for curved surfaces, such as boat hulls or hemispherical land shelters.

Boat builders have always been far better craftsmen than land builders; hulls must be watertight, strong, lightweight, and finely crafted—or you sink. Imagine the men who first ventured from land onto the seas: they not only had the desire to explore, but needed the ingenuity and talent to build seaworthy vessels. When they arrived in a new land, they could haul their boats up on the shore, turn them over, and have weatherproof shelters. And if they didn't do that in fact, they at least had the technology to build strong, tight structures.

Unfortunately, boatbuilder's skills have scarcely been applied to land shelters. Instead, entrepreneurs and politicians have restricted innovations, perpetuating the unequal distribution of goods which ensures their own continuity. As a result, land shelters are crude, and wasteful of resources as compared to sea (and air) structures. A boat must withstand pounding waves, yet carry a complete life-support system for its crew. An airplane is precisely designed and engineered, and the weight of each component is a major consideration.

It's well to look over the shoulders of the boat and airplane builders; and a technique well-suited to housing seems to be ferro cement. We have not yet built a ferro cement dome, but experiments are now under way in New Mexico, and we intend to try the technique soon.

Following are details gathered from reading, and talking to boat builders about the new material.

Advantages

Strength: one builder, when questioned as to the strength of his f.c. hull, picked up a sledge hammer and hit the bilge full force. There was a ringing noise as the hammer bounced back, and there was no mark on the hull. In another case, a ferro cement boat with 1/2″ thick hull hit a submerged rock at 12 knots, smashing the rock, and no damage to the hull. Also, it's flexible.

Fireproof: In 1964 the f.c. cruiser Mars exploded, throwing the cabin top 50′ in the air and the mast 200′ away. The contents of the boat burned completely. The only damage to the hull was a minor cracking at transom corners.

Durability: it grows stronger, rather than weaker with age.

Insulation: thermal conductivity is 1/6 that of steel.

Exterior: no paint or other surfacing material required.

Abundance of ingredients: principal ingredient is silicon, earth-surface's most abundant element.

Tools: can be done by hand, without expensive tools.

Cheap: it is.

Monolithic: Your shell is all one piece, without seams to seal. The fact that you are working with a liquid, which later hardens, gives much greater freedom and ease of design. Building with wood or metal you must assemble flat sheets like a jig saw puzzle. With reinforced concrete, you must build complicated forms. With ferro you can curve, involute, convolute, sculpt.

One of the disadvantages of ferro is that it's heavy. 3/4″ boat hulls weigh almost 11 lbs per sq ft, although a land structure, using less steel, would be lighter. Also, once built it's permanent and nothing short of a big bulldozer will move it.

HOW TO DO IT

If you are going to try ferro cement construction, two good sources of information:

Concrete Boatbuilding, Its Technique and Its Future
by Gainor W. Jackson & W. Morley Sutherland
$7.95 from Whole Earth Catalog
558 Santa Cruz Avenue
Menlo Park, CA 94025
or
John de Graff, Inc.
34 Oak Street
Tuckahoe, N. Y. 10707

Special ferro cement reprint issue, $1, from
National Fisherman
22 Main Street
Camden, Maine 04843

Limited Instructions

Pour a concrete floor and leave reinforcing steel sticking up at proper intervals to tie struts into. Construct framework of pipe, 1/2″ steel, or possibly conduit. (If conduit is strong enough, it is the easiest to assemble.) Boat hulls are framed of 3/4″-1″ pipe, spaced between 2′-3′, as required to maintain the shape of the hull.

1/8″ or 1/4″ spacer wire is then wired to the frame at about 3″ intervals. Boat builders then lay three or four layers of mesh, both on the inside and outside of the spacer wire, well tied to the spacer wire and frame. Laps in the layers of mesh should be staggered and loose ends well tied down. 1/2″ chicken wire or 16 gauge hardware cloth can be used for mesh.

In this, and in other aspects of f.c. construction, you should be able to use less steel, as the land structure is not subject to the stresses of the sea. You'll have to experiment—make test panels, hit them with a hammer, etc.

Note: at this point, you must make sure that the framework which you are about to apply f.c. to, is adequately braced. Martin Iorns of Fibersteel in Sacramento told me of a boat hull that deflected after it was completely plastered, and the builder didn't notice it until the next morning. A hole was dug with a dozer and the hull pushed in. Mistakes of this sort are irremediable.

Once it is framed and covered with mesh, you are ready to apply f.c., a mixture of

—2 parts sharp fine silica sand that passes through #8 sieve.

—1 part No. 5 Portland Cement. Replace 15-20% of the cement with a POZZOLAN (not "Pozzolith," or any brand containing calcium chloride). The pozzolan reacts with free lime in concrete to form an insoluble silica gel, strengthening the concrete and reducing permeability. Various types of pozzolan: fly ash, diatomaceous earth, others.

Use as little water as possible and mix in mortar mixer, which mixes more thoroughly than a concrete mixer. It must be completely mixed, no lumps. The drier the mix the stronger the shell.

Put on gloves to slap on mortar from outside. Helper on the inside checks carefully to make sure there are no voids. This is important, and you should take care to have a thoroughly plastered frame. If there are openings, inside man shoves wire through, indicating to plasterer where more need be applied. Put plastic sheet on ground to catch drop—surplus for re-use. When you've completed (either entire structure or a section), trowel. Use white cement (Riverside or Ideal-Medusa) for a smooth white finish—sprinkled on when troweling. Use plastic or wood finishing trowel. Cover with plastic or burlap bags and keep it moist for at least 7 days. If it sets too fast, it will crack and you will lose strength.

If you do it in sections, you will be applying new mortar to that which is set. This can be done, and a firm bind obtained at the cold joint, if you clean and roughen joint with wire brush and wisk broom (or vacuum cleaner) and use a wet-to-dry epoxy resin to insure good bonding.

The thinner the shell, the more steel is needed.

Synergy: MIT ferro cement tests with 6 layers of galvanized hardware cloth—16 gauge wire, 1/2″ mesh sustained loads of 1.5-1.8 that of the sum of 2 components (steel and concrete).

Ferro ideas

Try to build a framework where there are no hubs. For example, a geodesic dome could be framed with steel following the great circle arcs, bent at proper intervals, and wired together at vertices.

Flowing tubular structures should be easy—gentle curves.

A ferro cement sphere on a pedestal. Maybe octet truss floors inside. Find some ferro boat builders and get their advice. Domes should be easy compared to boats. The ocean is the testing ground for sturdy vessels.

From a Boat Builder to the *Whole Earth Catalog*

A successful experiment where we placed a sheet of polyethylene over an existing 16′, F.C. Whitehall boat, covered it with 4 layers of loose, ½″ chicken wire (left over from a 24′er), cemented it, and removed it after a 6 day cure, was inspired by the sand castle boat in this New Zealand publication. It is real rough, but I have been using it hard for a week with a 3½ H.P. Seagull with no sign of weakness, although it should have floatation or a deck.

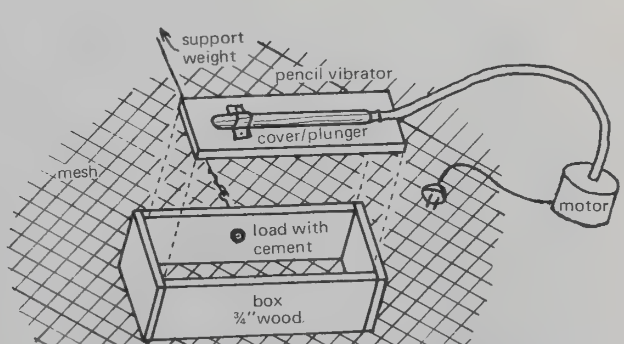
We built the boats upside down over plywood or plank molds (ribs, frames) that conform to the station lines in the profile view. The lofting is nothing more than graphing (like in school) where you make a series of measured cross points and connect them with a smooth line using a flexible piece of wood called a batten. You obtain the graph coordinates (the points on the same line) from the table of offsets.

Cover the set up molds with chicken wire (½″–¾″), 4 layers, a layer of lengthwise steel rods, and a layer of crosswise steel rods. We use high tensile spring steel, .85% carbon, full oil temper, because it comes in rolls, springs straight (if not coiled too tight), and makes the boat smooth. Cover with another 4 layers of chicken wire, and lace (sew) together with wire of about 22 to 16 ga; with lines of stitches 2″ to 6″ apart.

Although cementing can be done without special tools, a rented pencil vibrator, used with a box as shown speeds things up. Don't hang on directly to vibrator as it breaks up cells! Get plenty of materials. 50 bags of cement, for 36′ers. Penetrate, Penetrate, Penetrate! Use gloves. Leave openings for thru-hull fittings. Glass can be cemented in later for port lights. F.C. can be drilled with h.t. rod made into bits. Steer around rods in hull. Perhaps radiant heating pipe could be incorporated in F.C. shell. We are using variations of the above techniques.

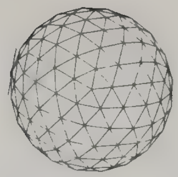
This material is not tedious to work in as most of the operations require no critical measuring or skill. It seems suitable for the humanistically, but not too technically, minded.

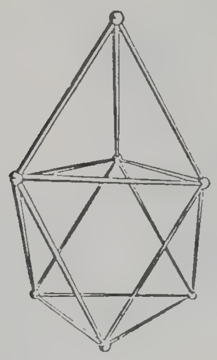
Derek Van Loan
Sausalito, California

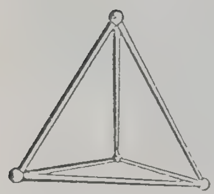


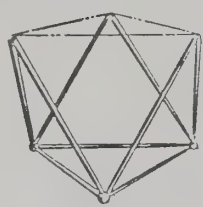
Sam Presley's Vibrator Box. Vibrating cover forces cement thru mesh like hypodermic needle. Start box at top and move down. Men inside stop cement with trowels and check penetration.

Fuller Patents









Patent No. 2,682,235, filed Dec. 12, 1951. "Building Construction." The basic geodesic patent. Very thorough and in the kind of Fuller language that makes you hold your breath until you reach the period at sentence's end. Explanation of geodesics, drawings of a 16-frequency triacon dome, hubs, trusses, and domes built of interlocking diamond sheets.

Patent No. 3,203,144, Filed May 27, 1960, "Laminar Geodesic Dome." In this patent on making domes of paper or light plastic parts, there are chord factors for a 3 & 4 frequency *diamond* dome, detailed drawings on weaving panels together to form structural membrane and details on making caterpillar geodesics.

Patent No. 2,905,113, Filed April 22, 1957, "Self-strutted Geodesic Plydome." How to overlap 4' x 8' sheets of plywood to form structural domes.

Patent No. 2,914,074, Filed March 1, 1957, "Geodesic Tent." Details on structural exo-skeleton, with canvas membrane suspended from vertices. Portable rock theaters?

Patent No. 3,197,927, Filed Dec. 19, 1961, "Geodesic Structures." How to frame domes in pentagons and hexagons, rather than triangles or diamonds, built-in tensioning rods, more.

Patent No. 2,881,717, Filed Jan. 24, 1955, "Building Construction." Paperboard domes, strut and membrane made of folded paper.

Patent No. 2,986,241, Filed Feb. 7, 1956, "Synergetic Building Construction." Octet truss—both hubs and folded plates. Details on hubs.

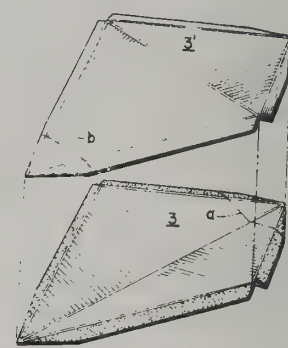
Patent No. 3,063,521, Filed Aug. 31, 1959, "Tensile-Integrity Structures." 13 pages of drawings of tensegrity structures.

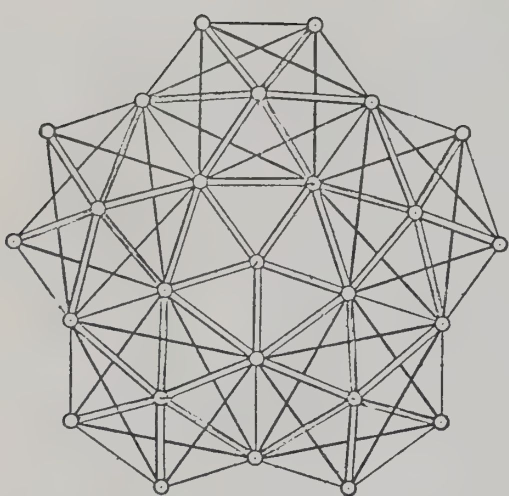
Patent No. 3,139,957, Filed Jan. 24, 1961, "Suspension Building." A dome based upon the principles of a suspension bridge. Not geodesic.

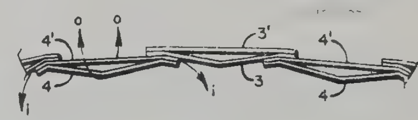
Patent No. 3,354,591, Filed Dec. 7, 1964, "Octahedral Building Truss."

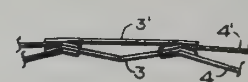
Obtain from: U. S. Dept. of Commerce
Patent Office
Washington, D.C. 20231

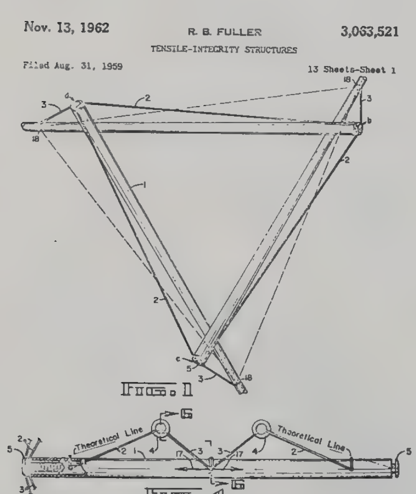
Special air mail handling, 50¢ each patent.

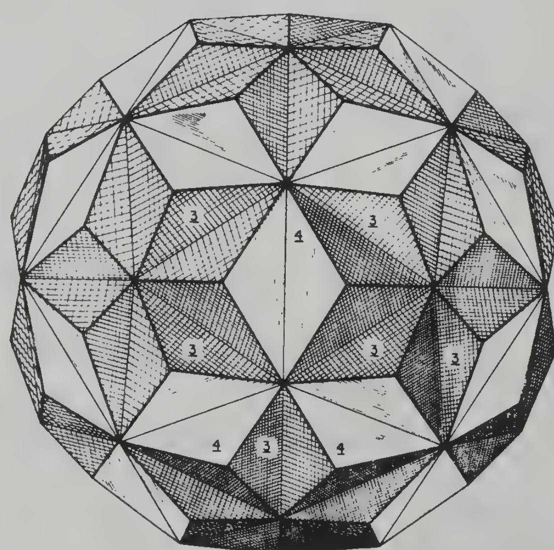


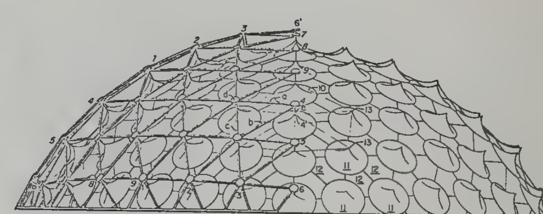












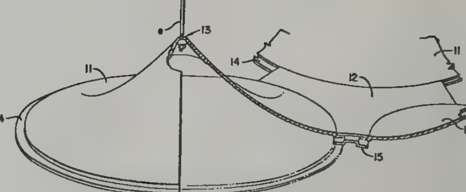


FIG. 2

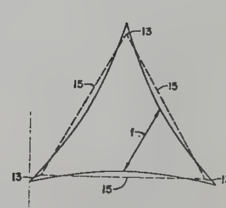


FIG. 3

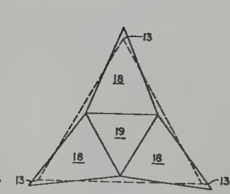


FIG. 4

GEODESIC LICENSE AGREEMENT

There are 20-30 geodesic license holders in the U. S. If you are going to build domes for re-sale, you pay $.05 per square foot of exterior dome surface area to Fuller's office. This would amount to about $50 for a 24' dome.

If you are just going to build one dome for yourself, or as an experimental project, write Fuller's office. They generally charge $1. in such cases.

You can also obtain, upon request, a list of all franchise holders.

Write:

R. Buckminster Fuller
Box 909
Carbondale, Illinois 62901

Attn: Dale Klaus

First, there is a need for building codes. Don't be so bitter that you fail to recognize this. If not for the codes, and building inspectors, slipshod contractors would be building far worse (it's hard to believe) than at present. Yet although the codes were designed with some justifiable purpose, they do tend to discourage individual initiative and almost prohibit innovations. This is because they are based upon compression type (beam on post) structures, and the structural strength of domes cannot be explained in these terms.

I have always assumed that building inspectors are human and have much greater luck in explaining things to them, rather than fighting them. The farther you are from a city, the fewer problems you will encounter, but if your site does fall within the jurisdiction of local codes, these are some observations and experiences that may be helpful:

Building codes do not cover domes. There's nothing in the book about tension (the top of the dome, although rock solid, does not have a post under it). You don't need studs every 16", and the entire structure is both walls and roof.

In building your own dome you short-circuit the entire team that makes buildings, which includes:

1) architects and engineers. You may consult with them, but both the architecture and the engineering of a dome are simple and you don't have to pay 10 or 15% of the building costs to these two.

2) Union help. Not needed, as the customary handskills are not necessary.

3) Banks. You can build the shell, move in, then add to it as money becomes available. No mortgage enslavement. I was astounded to learn recently that interest on a typical mortgage loan *doubles* the cost of a building. If you borrow $15,000, you pay back, over the years, over $30,000.

4) Contractors. You are on your own, and this saves 10%.

When you bypass these interests, you're in trouble, as they are the team—along with building inspectors and materials dealers—in charge of construction in America. You have the choice of several alternatives.

1) You may be in an area not subject to inspectors. No problem here.

2) If you do come under the codes, several possibilities:

   a) *exemption:* sometimes the codes, or local county ordinances allow you to build a barn, greenhouse, studio, temporary building, tent, a sculpture, etc., without a permit. Check codes and talk to inspectors—be vague until you find out how to classify it. Start by using telephone.

   b) *summer camp:* in California (perhaps also in other states), tents intended for use at a summer camp do not fall under jurisdiction of the building inspector. Get Calif. Organized Camps pamphlet:

   > "Laws and Regulations Relating to Organized Camps—Excerpts from the California Health and Safety Code and the California Administrative Codes—1968". Can be obtained from State of California, Dept. of Public Health, 2151 Berkeley Way, Berkeley, CA 94704.
   >
   > The health department is in charge of camps, and will use the building inspector for advice. However, "tent platforms" under 25' any one dimension can be built without usual permits or fees. Perhaps your dome qualifies as a tent:
   >
   > "Whenever the term tent or tent structure is used, it shall mean any shelter of which 25% or more of the walls, or roof, or both are constructed of or covered by or protected by, canvas or any other fabric materials . . ."

   Be cool on this one, as a rush of hastily-concocted summer camps could rescind the law.

   c) *strength test:* Section 107, Uniform Building Code says that when a structure does not come within the code, the building inspector shall devise a test for structural strength:

   > Whenever there is insufficient evidence in compliance with the provisions of this code or evidence that any material or any construction does not conform to the requirements of this code, or in order to substantiate claims for alternate materials or methods of construction, the Building Official may require tests as proof of compliance to be made at the expense of the owner or his agent by an approved agency. . . . If there are no appropriate test methods specified in this Code, the Building Official shall determine the test procedure. . . . "

   The inspector may interpret this as meaning that you have to hire a structural engineer, but it looks as if it is up to him to devise a test. A simple strength test is to load a top section of the dome with sandbags. Since the dome is spherical, and more or less equally strong throughout the entire skin, whatever load you place on the top is equivalent to the same force wind blowing from the side. Perhaps easier than sandbags would be some kind of containers you'd fill with water—easier than lugging sandbags.

   Some extensive structural tests of plywood domes were made by The H. C. Nutting Co., 4120 Airport Road, Cincinnati, Ohio 45226, in 1958-59.

   Two Pease domes were tested—similar in construction to the Big Sur dome, p.13 . One was 26' diameter with 2 x 4 strut space-frames, the other was 39' diameter, with 2 x 2 strut space-frames. Both were sheathed with 5/16" plywood.

   The domes sustained loads of 100-120 lbs per sq. ft., sand loaded onto the apex of the dome and its six converging triangles. In another test, a North American AT–6 Army trainer with 650 hp Pratt-Whitney engine was used to produce a wind of hurricane force (in excess of 70 mph). The airplane was backed up to the dome, and tried from different angles. The reports include detailed tabulations of deflections. The wind machine didn't faze the dome.

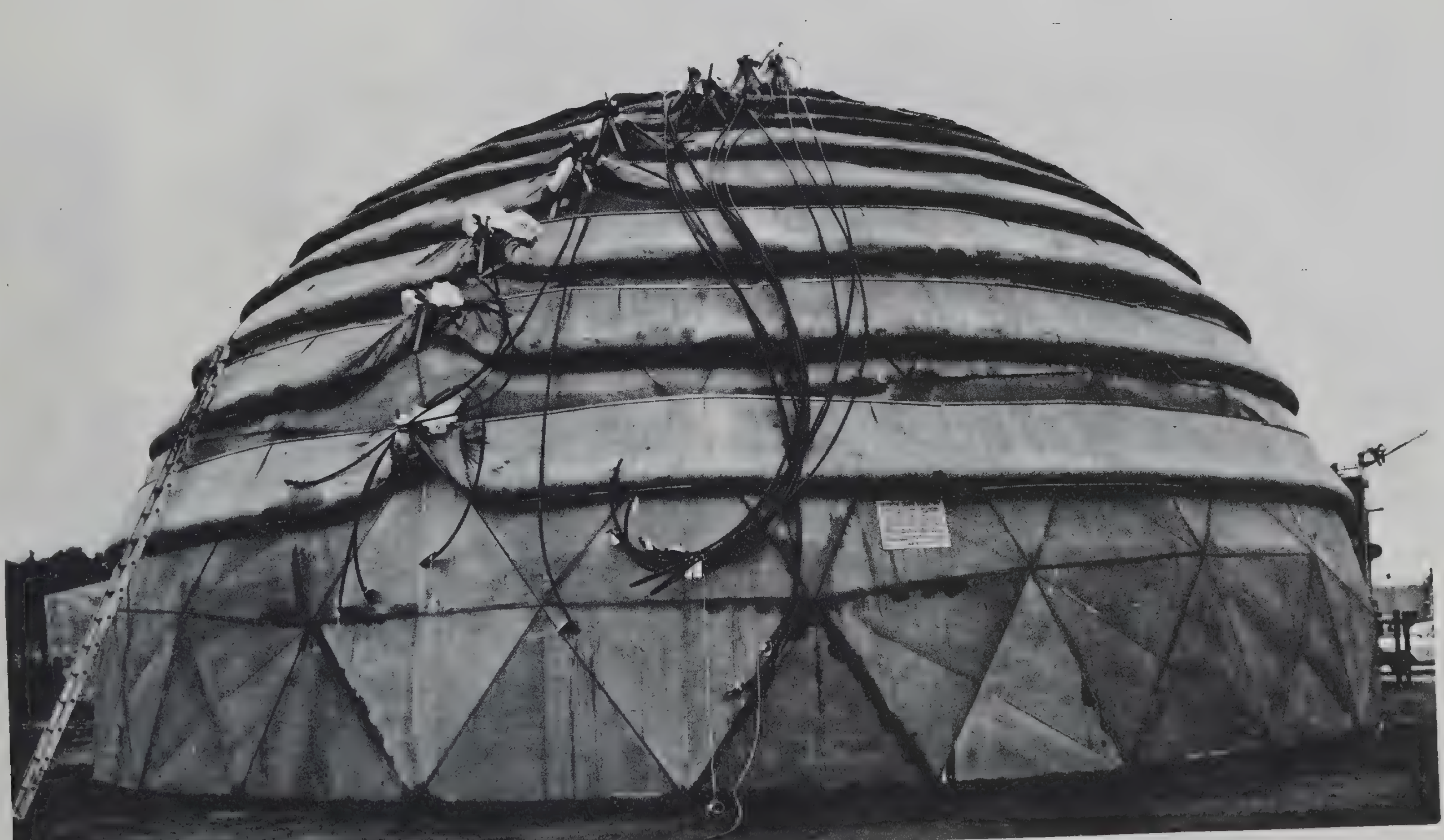
   The Uniform Building Code requires *any horizontal projection* in a dwelling to support a live load of 40 lbs per sq. ft. The structure must also support "dead load"—weight of the structure itself. So this type dome, with only 5/16" plywood skin, is over twice as strong as required by the codes.

   d) *mobile home:* put wheels on your dome. Regulations on mobile homes are much more lenient, and a dome more closely resembles a mobile home than a typical heavy house: it's 1/10 the weight, and with proper design, you can easily move it. I don't think it even has to *roll* on the wheels; just putting them on may qualify for the classification.

3) See a lawyer. It seems that it ought to be o.k. for a man to build whatever he wants on his own property as long as he does not intend to rent or sell. You'd perhaps write the building inspector a letter absolving his department of any liability, and work out details with a lawyer.

Whatever you do: try to make it possible for more domes to be built in your area.

Building Inspector



Test on plywood Pease dome by H. C. Nutting Co., Testing Engineers, Cincinnati, Ohio. Test data available from Pease Woodwork Co., Hamilton, Ohio. These domes have approval of the International Congress of Building Officials. Dyna Domes of Phoenix has also made extensive structural tests, and has FHA approval of domes.

centering

by Alan and Heath

Swami Kriyananda lives in a 26', 2-frequency hemisphere plywood "Pease" dome, set up on a 3 foot wall.

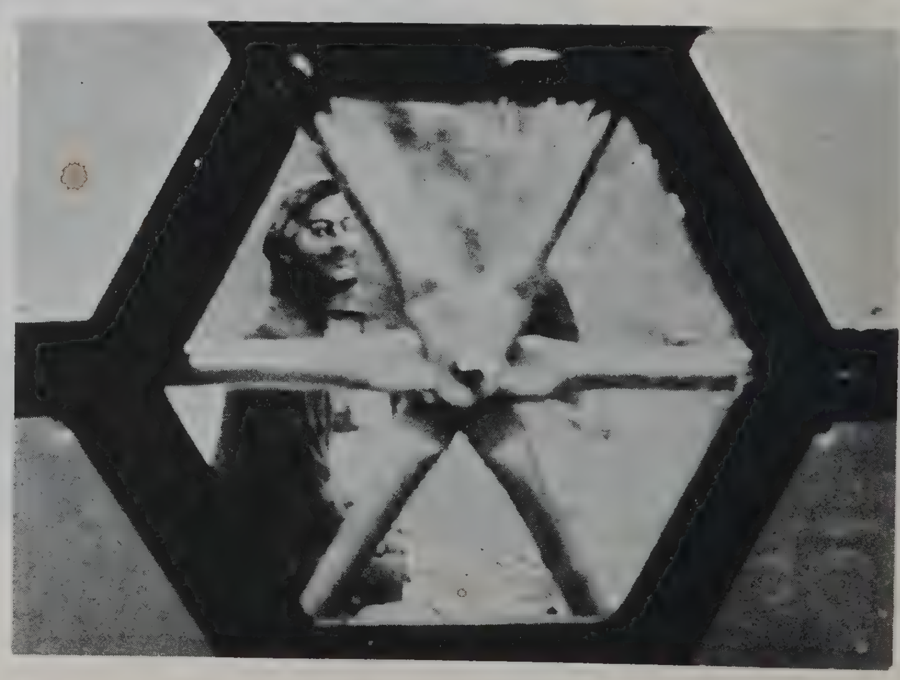
When Kriyananda was in India, a number of years ago, he was thinking about various structures and which would be best suited for meditation.

A rectilinear structure is too confining and can give one the feeling of being boxed in.

An arched ceiling is better but still confining and heavy.

A dome ceiling like in the great cathedrals, he thought, is still better but still there is the heaviness and great walls and size. A geodesic dome is by far the best. It is truly an extension of the mind and resembles the Sahasrara or Lotus of a Thousand Petals, our seventh chakra located at the top of our heads.

Before moving into our dome (the design and construction is described in Bubble Dome, p. 24), we lived in a 16' Sioux Tipi. I spent many weeks hunting down the poles in the woods surrounding our area. The tipi sold us on the idea of an undivided circular room with a symmetrical open ceiling coming together at the top. Along with the igloo and yurt, the tipi is an original shape. The mobile Plains Indians perfected its design. It is the architecture of motion. It is made up of triangles that can be collapsed and dragged on its struts (poles) behind a horse. The greatest advantage of a tipi is its portability. As we get farther along with domes, we find more avenues to increase the portability (if one so desires it) of domes.



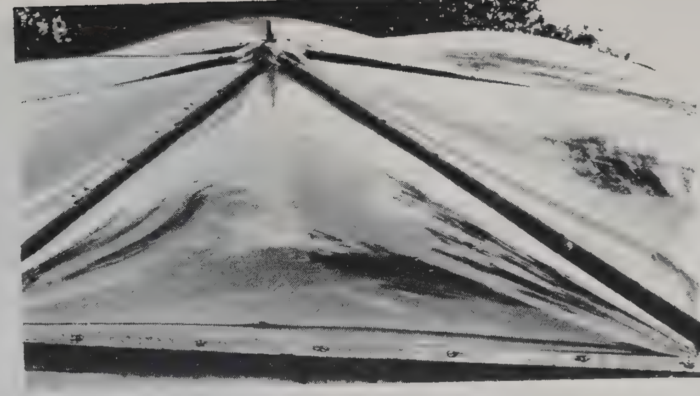
The question of the choice of materials in our present day comes up in many contexts. In choosing materials you should respect them. The materials should be treated as something sacred, something we have been given to be transformed into something else. The more sacred we make our materials the more interesting become the ways we find to use any leftovers. By treating our materials with reverence we treat ourselves with respect and necessarily build good vibrations into our dwelling.

Maybe someday all our buildings will become temples.

n our dome we used a lot of plastic and learned to treat as a sacred substance. Some people feel that plastics re offensive, but this is mainly because sometimes we se the terms "plastic society" or "plastic people". lastics do represent a trend of our contemporary world. They may be a contributing factor, but they don't account or the alienation and gross materialism of our age, nor eed they be condemned to be used only by the people who consider nothing, not even the air or soil or water, s sacred.

t is certain that plastics are a better use for petroleum han fuel for internal combustion engines. In our dome ve used the same vinyl as all our other domes and found hat its practical virtues are many. It is lightweight, conomical, flexible, easy to work with, transparent, durable, and children can't cut themselves on it or reak it.

A few of the questions concerning plastics are that we have to consider the pollution caused by their manufacture and presently plastics are only produced by larger industry. There is, however, much room for the small craftsman on many levels. A hidden advantage of the use of plastics is that since internal combustion engines must be phased out, the big industry and investment behind petroleum will still have a place to work before a whole other phase takes over when the earth runs out of petroleum. A few more general considerations concerning petroleum: obviously we shouldn't pollute our ocean in trying to obtain it; also, sucking it out from under the earth's crust may contribute to future earthquakes.



The frame of our dome is metal. It is important for both the obvious physical reasons and also for the more subtle metaphysical reasons that domes be grounded. This importance also extends to people who sleep in their trucks and campers: they should ground them at night. You will notice that you will sleep more peacefully and have fewer dreams relating to what goes on in the dome or to driving and the road.

Windows and ventilation are two more basic questions. Fuller says it's good to have a window or so at ground level. We reserved this spot for our altar. It's good when designing a dome to plan to have an altar or special place along one section of the side, preferably in the east. Also, make sure you plan to have sufficient openings for adequate ventilation. It's easy to figure out a way to have at least one top triangle hinged and have it open via a big spring.

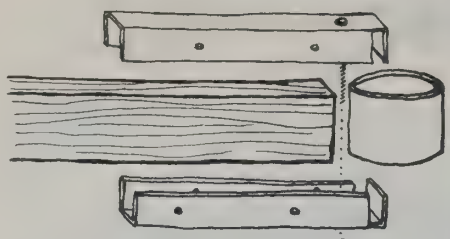
Besides the main entrance in the floor we have two side triangles that open onto the platform (our balcony) and two small openings in the back that are just above the ground for the dog to enter and for us to pour out our biodegradable soap water and leftover tea.

We planned the layout of our dome in correlation with its intended use. Our bed is up about 5 1/2', with storage underneath and the stove and kitchen are up against the sides. The floor is left open—a large open area for work, play and yoga classes. Our classes are incredible. Domes are such a centering trip. One's eyes can easily center on any of the mandalas formed by the struts.

Even our conversations are more centered because we sit in a circle and stay in closer touch with each other. All vibrations—sound, light, heat and all our awareness —begin in the center and radiate outward and rebound back and forth from the center. Consequently, chanting is mind-expanding and all-encompassing.

Living in a spherical single unit home makes us wholer people. We feel more whole and have our whole trip around us. We stay more in touch with each other and our friends and also this wholeness has a healthy effect on our possessions, our wants and desires. Feeling whole and centered is crucially important, and domes surely can contribute to this.

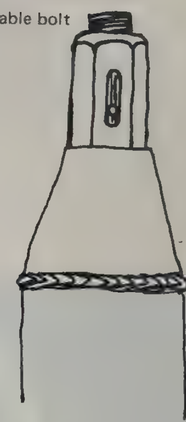
Hubs



Dyna Domes hub for wood struts

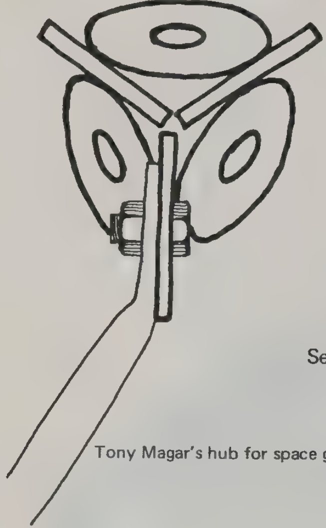
Fisheye of sky and clouds shot through pipe hub

spring loaded retractable bolt



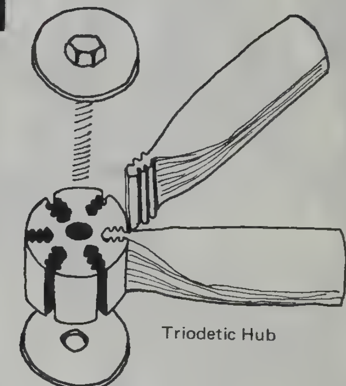
Mero-Triagonal Hub

washers welded together



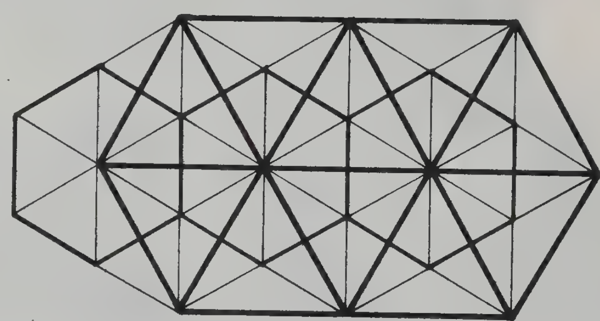
Tony Magar's hub for space grids

Send us your hub ideas.



Triodetic Hub

The above two hubs from *Space Grid Structures*, by John Borrego. See bibliography. A beautiful book for hubs, trusses, geometric patterns.

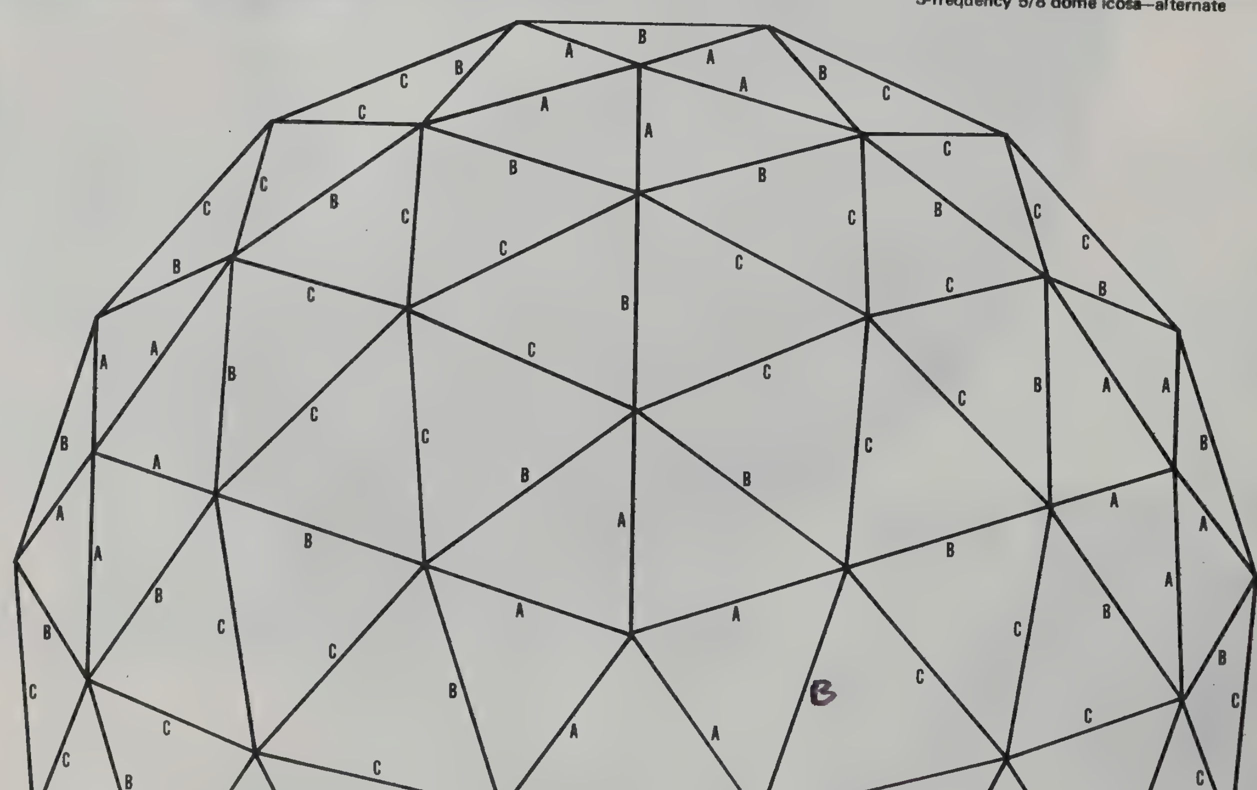


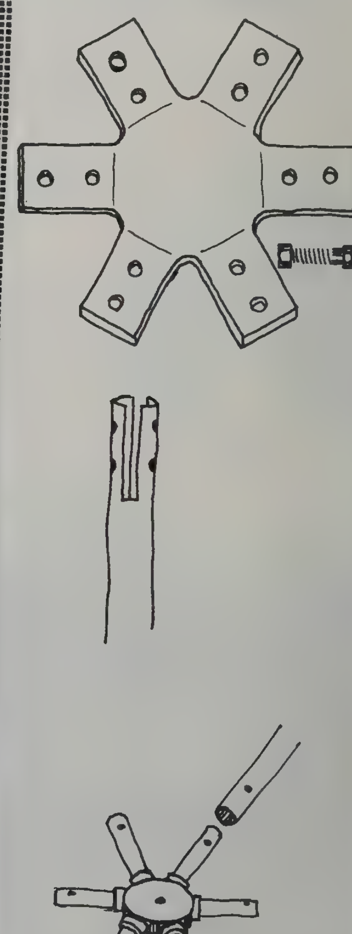
section of EXPO '67 double grid dome

Drill holes in number 3 dog food cans with a sharp rock or stick, insert old car antennas and glue with wetted Kilpatrick's. Coat bread with grease when set, to waterproof.

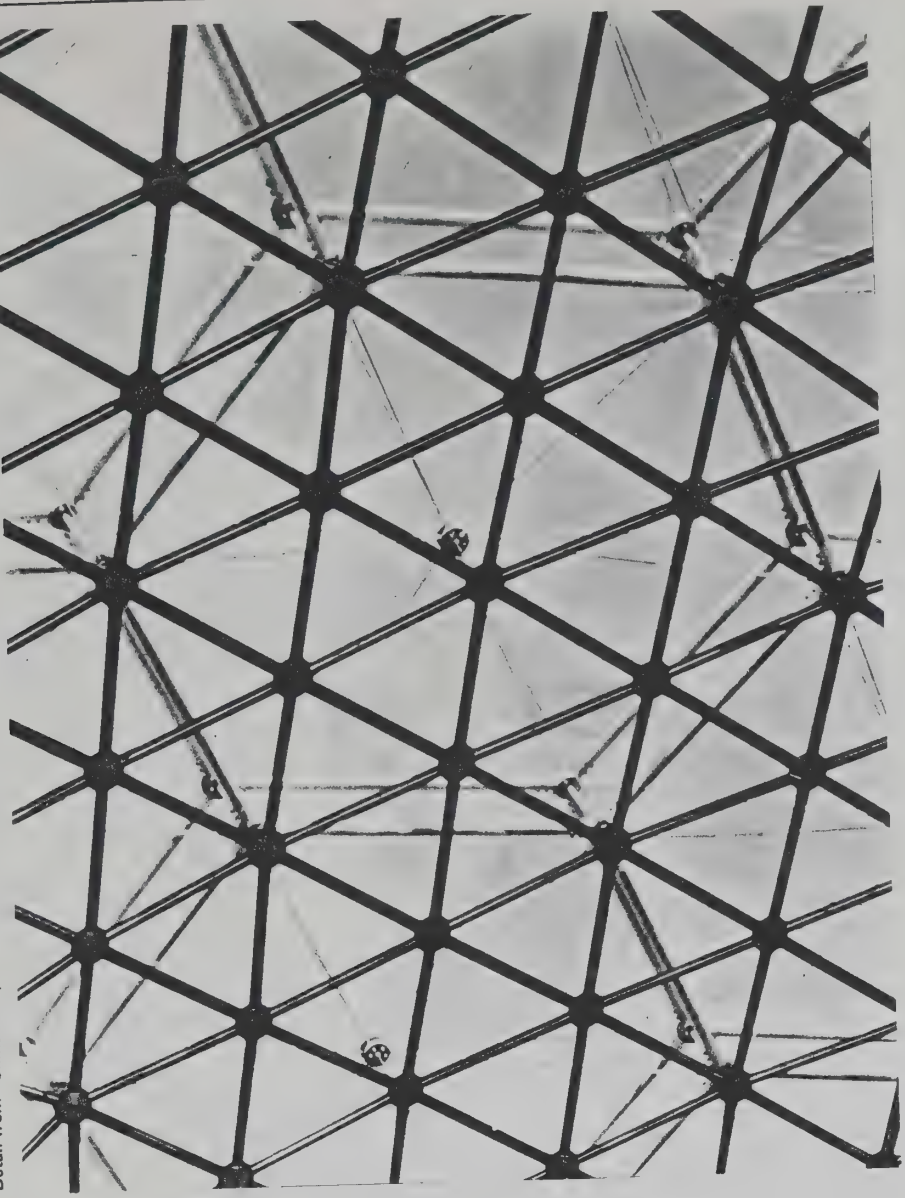
DIAGRAM FOR ASSEMBLY

3-frequency 5/8 dome icosa—alternate





Two hubs for tube frames by Jay & Kathleen



Detail from "Climatron", Botanical Garden in St. Louis.

what size?

The size you *want* your dome to be is not the only factor to be considered when deciding the exact size and frequency. Your choice will also depend upon the materials and *sizes* of materials available, as well as the tools you can utilize. You should also consider waste. All these factors are interrelated. It will save you time and money if you carefully untangle them before you begin building.

Start with an approximate dome size that you think will meet your space needs, and make a decision as to the probable materials to be used. It has been found that 3-frequency often makes sense in the size range from 15 to 40 feet. Arbitrarily start with that. Using the chord factors ("LENGTH" in the tables) for 3-frequency, determine what size the largest triangle will be for your proposed dome. Then lay out a scale drawing of this triangle superimposed on a scale drawing of your proposed material *accurately* on graph paper. See if it can be made from the materials you have chosen without excessive waste or complex piecing, and without overstressing the materials. It will often be found that a larger dome can be made at no increase in cost by adjusting the diameter to a size that will more efficiently use the materials. In fact, there is usually an *optimum size dome for a given material and frequency.* Example: Because of the standard 4 x 8 size of plywood, 24' is the maximum size dome you can economically make from plywood in 3-frequency without waste or very complicated assembly of small plywood parts to make the triangles. (See Pacific Dome) There will be no advantage at all to making a 22 or 23 foot dome; you'd just waste plywood. A 27' dome, for instance, would be very difficult to make and would also waste wood, unless you use hub windows (See Big Sur Dome). *This means that the exact size of a dome is usually dictated by the size of material.* You can try things on graph paper and then see what size dome you will get by a little algebra:

$$\frac{\text{strut (triangle edge) length (in inches)}}{\text{chord factor}} = \text{dome radius (in inches)}$$

It sometimes happens that to make the dome a good size for one material will waste another because of size limitations. In this case, waste the least of the more expensive material. As an example, the Bubble Dome frame is conduit which comes only in 10' lengths. Obviously it is most economical to get two struts from one 10' length. There are three different strut lengths in a 3-frequency dome, so the maximum strut you can get from a conduit length is a combination of one longest strut and one shortest strut. This results in a dome of about 27 feet. However, at the time that the Bubble Dome was made, vinyl was only available in a size that permitted a 20' dome in 3-frequency. Making a dome *less* than 20' would result in wasting both conduit and vinyl; the smaller dome would cost the same as the 20-footer, and the waste would be of an unuseable sort. (The 20' size wastes conduit, but conduit is cheaper than vinyl.) If we had wanted a *larger* dome from these materials, we would have had to *raise the frequency*, and compute the diameter that would require the largest triangle in that frequency to be about the same size as the large triangle in the 20' 3-frequency. If we had gone to 4-frequency, we would have found 26' to be the maximum size that could be made from vinyl and conduit with a minimum waste of expensive vinyl. *So we see that one reason to increase frequency is to get a larger dome from materials that are available only in small sizes.*

Another reason to increase frequency is to be able to make a larger dome from materials that have a structural limit on size. Structural considerations usually have to do with the distance that a part must span. This distance depends upon the material and the expected loads, but as a general rule, the "slenderness ratio" (the length/thickness ratio of a strut) should not exceed 24-to-1 for wood and 30-to-1 for metal unless there is additional structural strength coming from other parts of the dome. If the dome is not to be skinned, these ratios can be much higher. An engineer should be consulted if you aren't sure, particularly for larger or highly loaded domes. Anyway, you *raise the frequency to keep the component spans within allowable limits.*

You might wish to *use a higher frequency for esthetic reasons* to get a smoother curve or more visually delicate structure. The next paragraph will show what is involved. Remember that if the frequency is raised beyond what is required structurally, you should reduce the size of the structural members accordingly so as to avoid bulky-looking overdesign.

As the frequency is raised, the curve of the dome gets smoother. The angles under the hubs, however, get wider—closer to 90° (the "AXIAL" in the table)—making it easier for a load to punch in a hub or vertex. For this reason, *increased frequency requires better workmanship;* a smaller and smaller error results in dangerous weakness as the frequency rises. For this reason, it is well to stay within 6 frequency unless you can do precise work and know what you are doing. It isn't practical to go above 12-frequency with a strut dome; larger domes are actually double walled either with trussing systems as in EXPO '67 dome, or an involuted surface giving greater thickness to the structure as in the Laminar Geodesic (see Fuller Patents).

One more factor affects the size decision: the cut-off line (where you slice the sphere). For domes below 25 feet diameter, you'll have to choose a cut-off line resulting in *more* than a hemisphere if you want to be able to stand up near the walls. For domes larger than 25', a hemisphere or less will do. You can draw it on graph paper to check. Most of the domes shown in this book are 24 foot diameter (or smaller) 5/8 spheres. Remember that a 3/8 sphere uses 40% less material than a 5/8!

The "COMPLETE STRUCTURE" "LENGTH" factor in the tables is useful for finding the increase in the total quantity of strut as you raise the frequency. Keep the dome radius the same. Multiply the radius times the complete structure length factor for the frequencies in question to see how much more strut the higher frequency will use. The V(G), E(G), F(G) figures in the tables will show you the increase in *number* of struts, hubs and faces. The skin *area* will be about the same from one frequency to the next, but the sensible way of cutting it out may change drastically. You can check it out on graph paper. Be accurate in your graph paper work. Use a sharp pencil and a ruler. Careful thought figuring these things out will result in the most economical dome for your intended use. It will *feel* right too.

chord factors and angles

All these figures are for icosahedron based "alternate breakdown" (see page 7) geodesic spheres as discovered by R. Buckminster Fuller. The numbers are from computer readout generated by a program written by J. D. Clinton for NASA. "Structural Design Concepts for Future Space Missions," *Progress Report*, NASA Contract NGR 14-008-002.

Figures given do not refer to structural strength. If you aren't sure of strengths of various materials, you should get expert help. Generally speaking, amateurs shouldn't attempt domes larger than 40'. The higher the frequency, the flatter the angle of the dome's faces (the "dihedral" below) and the more critical is accurate workmanship to prevent "popping in" of a vertex under load. Big domes usually are made from folded plates which give the skin a large cross section, or they are made from two domes of the same or different frequencies but different size, one inside the other and laced together with additional struts, as at EXPO '67.

An icosahedron has twenty identical equilateral triangle faces and twelve pentagonal vertices. The diagram here is *one face* of the basic icosahedron, divided into the number of additional faces as required by the desired frequency. The various lengths of edges of these additional faces cause the icosa face to bulge into a more spherical shape. For a given diameter, the higher the frequency, the more sphere-like the icosahedron becomes. The little numbers on the diagram are *vertex identifications,* and are referred to in the tables starting with 0,0. The following is an explanation of the tables, and all examples given are for a "two frequency" breakdown. Note that the diagram, regardless of what portion of it is used, *does not imply size at all.* Starting at the top of a section in the tables:

FREQUENCY 2 Icosahedron—means (obviously) a 2-frequency breakdown of a basic icosa.

Looking at the diagram we see that for a 2-frequency breakdown we use only that part of the diagram outlined by 0,0 2,0 2,2, because that area represents *one icosa face* broken into *two parts* at the edge. Remember that just because this area on the diagram is a small corner of the diagram, this does not mean that 2-frequency breakdown is in any way "small". The diagram is just that: a diagram. So we will ignore the rest of the diagram, and work from the part of it that defines "2-frequency" (see Fig. 1).

V(L)=6 means that the *number of vertices* in one icosa face of this particular breakdown is 6.

E(L)=9 means that the *number of edges* in one icosa face is 9.

F(L)=4 means that there are 4 *faces* in one icosa face when broken into 2-frequency.

The figures V(G) = 42, E(G) = 120, F(G) = 80 are the number of vertices, edges, and faces in an *entire sphere* based on the 2-frequency breakdown of the basic icosa.

LENGTH 1,1 1,0 This means we are talking about the strut that has vertex 1,1 at one end and vertex 1,0 at the other. This length number is also known as the CHORD FACTOR, and is called that in the rest of the chapters of this book. To use it, multiply this chord factor by the *radius* of the dome you want to build. The answer will be the length of that particular strut in the size dome you desire; it will be in the *same unit of measure as you measured the radius.* In other words, if you give the radius in inches, the strut length will be given in inches. NOTE: The dome diameter that will result from using the chord factors might vary a few inches due to rounding off the numbers in the calculations and inaccurate workmanship. For this reason it is usually safer to make the foundation or the floor after you make the dome. In making this calculation, do it to *at least* the fourth decimal place, and double check your work. It is essential that the workmanship be accurate. And, remember . . . this *length is vertex to vertex.* If you are using hubs, this number will *include* the hubs, so the *actual cut length of the struts will be less than this number.* It will be this number *minus* the diameter of a hub. It's easy to make a mistake here. Think it out carefully, and again in the morning.

AXIAL 0.0 1,0 1,1 refers to the angle between a line drawn from the center of the sphere (0.0) and vertex 1,0, and the strut 1,0 1,1 (Fig. 2). It is the angle that a strut meets its hub from the side view. Note that it is *not* the entire included angle under a hub, but only to the line from the hub to the sphere center. The first value is DEGREES. The second is RADIANS. 90° minus the axial angle equals angle you cut or bend struts.

FACE 1,1 0,0 1,0 refers to one angle of the triangle described by these points. The angle given is the angle whose apex is at the second vertex identification shown; in this case, 0,0 (Fig. 3). Face angles refer to angles of triangles generated by chord factors, not spherical angles on a true sphere. Again, the first number is given in degrees and the second in radians.

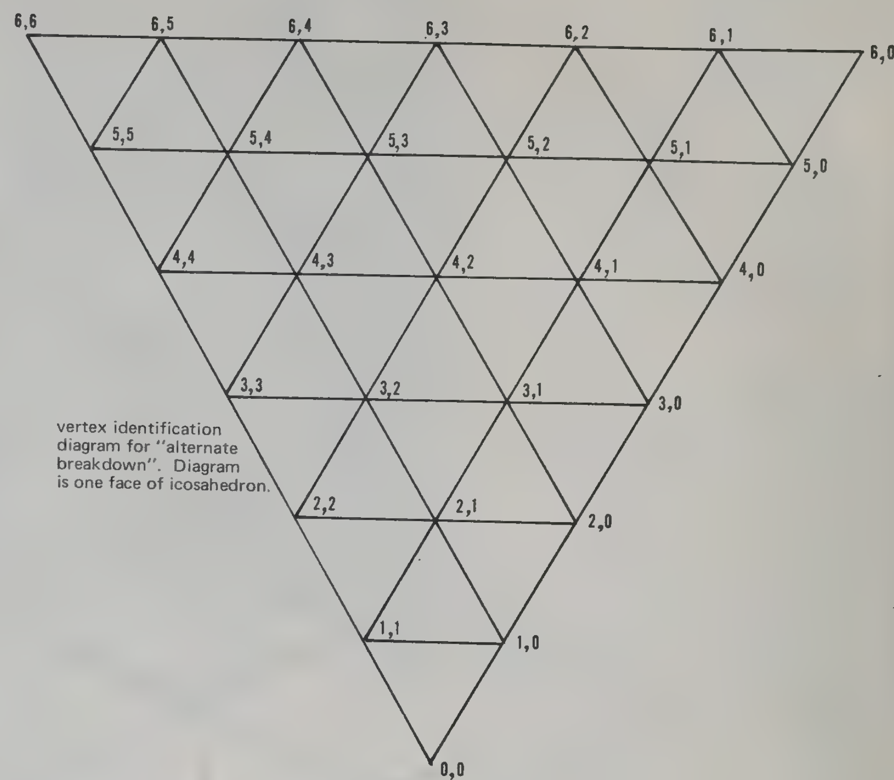
DIHEDRAL 1,1 1,0 refers to the angle between the two faces that share edge 1,1 1,0. It is the *total included angle* and again is given first in degrees and then in radians. See Fig. 4.

ONE FACE AREA gives the area of one complete icosa face in 2-frequency.
VOLUME gives the volume of that face between it and the flat face of the icosa. (In other words, it shows how much more "spherical" it is than the basic icosa.)
LENGTH gives the total edge length in the 2-frequency facets of one face in 2-frequency.

COMPLETE STRUCTURE is likewise for the entire "sphere" in 2-frequency.

These numbers are like the chord factors in that you multiply them times the radius of the intended sphere to get the actual figures. The answer will be in the same unit of measure as the radius is given.

The various "paragraphs" in the tables will yield all the necessary information if you keep in mind that, just as the face in the original basic icosahedron was an *equilateral triangle,* the 2-frequency face 0,0 2,0 2,2 is *also equilateral* and thus *symmetric.* This means that the three triangles shaded in Fig. 5 are exactly the same. It also means that the center triangle is equilateral. 3-, 6-, 9-frequencies (multiples of three) have a point at the center of the face instead of a triangle as in this case. Fig. 6 shows the 3- and 4-frequency breakdowns. The triangles of the same shading are the same in all respects except left and right orientation. Note that the pattern of sameness is symmetric about the center of the triangular array of whatever breakdown frequency you are using.



vertex identification diagram for "alternate breakdown". Diagram is one face of icosahedron.

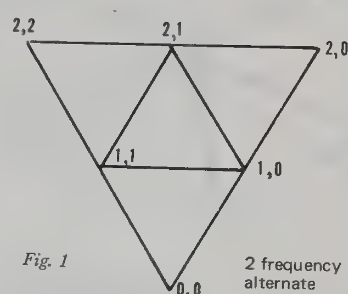


Fig. 1 2 frequency alternate breakdown

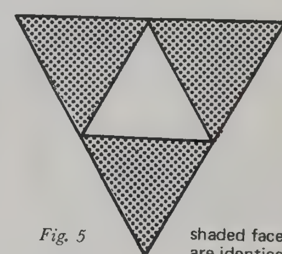


Fig. 5 shaded faces are identical

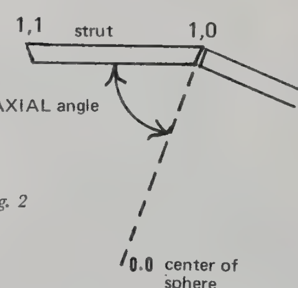
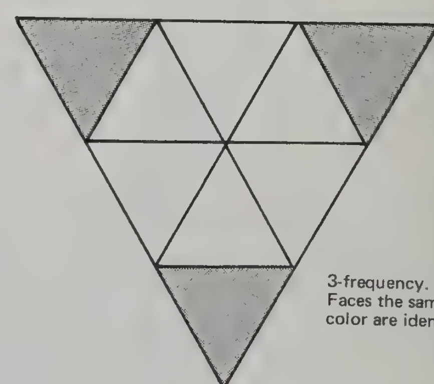


Fig. 2



3-frequency. Faces the same color are identical.

Fig. 6

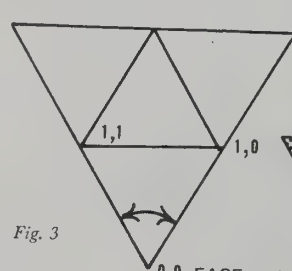
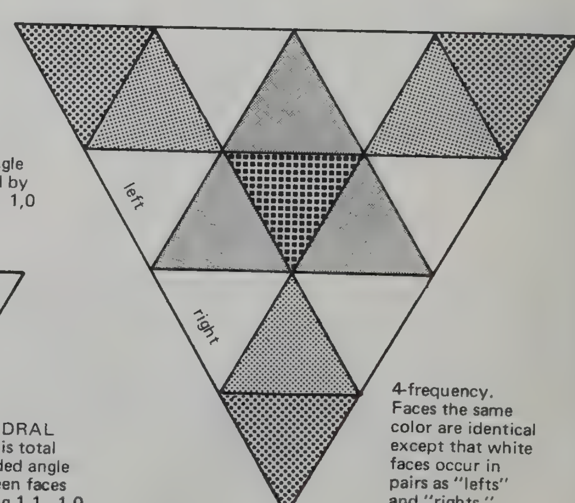


Fig. 3 FACE angle described by 1,1 0,0 1,0



4-frequency. Faces the same color are identical except that white faces occur in pairs as "lefts" and "rights."

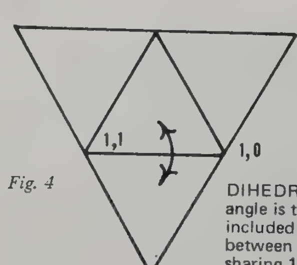


Fig. 4 DIHEDRAL angle is total included angle between faces sharing 1,1 1,0

NOTE: There is nothing in these figures that tells you where convenient cut-off places are for having your dome meet the ground. Nor will the figures tell you if a cut-off line will be in one plane. A 2-frequency dome can easily be cut at the true equator, but a 3-frequency can't. You have to make a model. Assume a pentagon to be at the apex of the dome as a start until you see what you are doing in the model.

1-FREQUENCY ICOSAHEDRON, ALTERNATE

V(L) = 3 E(L) = 3 F(L) = 1

V(G) = 12 E(G) = 30 F(G) = 20

LENGTH	1,1	1,0		1.05146222	
AXIAL	0.0	1,0	1,1	58.282525	1.017222
FACE	1,1	0,0	1,0	59.999998	1.047198
DIHEDRAL	1,1	1,0		138.189684	2.411865

ONE FACE		COMPLETE STRUCTURE	
AREA	0.478727	AREA	9.574541
VOLUME	0.126808	VOLUME	2.536151
LENGTH	3.154387	LENGTH	31.543866

2-FREQUENCY ICOSAHEDRON, ALTERNATE

V(L) = 6 E(L) = 9 F(L) = 4

V(G) = 42 E(G) = 120 F(G) = 80

LENGTH	1,1	1,0		0.61803399	
AXIAL	0.0	1,0	1,1	71.999996	1.256637
FACE	1,1	0,0	1,0	68.861974	1.201868
FACE	1,1	2,1	1,0	59.999998	1.047198
DIHEDRAL	1,1	1,0		161.970892	2.826925
LENGTH	2,1	2,0		0.54653306	
AXIAL	0.0	2,0	2,1	74.141260	1.294009
FACE	2,1	1,0	2,0	55.569010	0.969862
DIHEDRAL	2,1	2,0		157.541075	2.749611

ONE FACE		COMPLETE STRUCTURE	
AREA	0.583297	AREA	11.665931
VOLUME	0.182936	VOLUME	3.658712
LENGTH	5.133300	LENGTH	69.874022

3-FREQUENCY ICOSAHEDRON, ALTERNATE

V(L) = 10 E(L) = 18 F(L) = 9

V(G) = 92 E(G) = 270 F(G) = 180

LENGTH	1,1	1,0		0.40354821	
AXIAL	0.0	1,0	1,1	78.359272	1.367627
FACE	1,1	0,0	1,0	70.730537	1.234481
FACE	1,1	2,1	1,0	58.583164	1.022469
DIHEDRAL	1,1	1,0		168.641064	2.943342
LENGTH	2,1	2,0		0.41241149	
AXIAL	0.0	2,0	2,1	78.099906	1.363101
FACE	2,1	1,0	2,0	60.708416	1.059562
FACE	2,1	3,1	2,0	60.708416	1.059562
DIHEDRAL	2,1	2,0		166.421442	2.904602
LENGTH	3,1	3,0		0.34861548	
AXIAL	0.0	3,0	3,1	79.961621	1.395594
FACE	3,1	2,0	3,0	54.634727	0.953556
DIHEDRAL	3,1	3,0		165.564739	2.889650
LENGTH	3,2	3,1		0.40354822	
AXIAL	0.0	3,1	3,2	78.359272	1.367627
FACE	3,2	2,1	3,1	58.583164	1.022469
DIHEDRAL	3,2	3,1		165.542280	2.889258

ONE FACE		COMPLETE STRUCTURE	
AREA	0.607532	AREA	12.150641
VOLUME	0.197070	VOLUME	3.941391
LENGTH	6.987451	LENGTH	106.725645

4-FREQUENCY ICOSAHEDRON, ALTERNATE

V(L) = 15 E(L) = 30 F(L) = 16

V(G) = 162 E(G) = 480 F(G) = 320

LENGTH	1,1	1,0		0.29524181	
AXIAL	0.0	1,0	1,1	81.510921	1.422634
FACE	1,1	0,0	1,0	71.331604	1.244971
FACE	1,1	2,1	1,0	60.159766	1.049986
DIHEDRAL	1,1	1,0		172.197790	3.005419
LENGTH	2,1	2,0		0.31286893	
AXIAL	0.0	2,0	2,1	80.999996	1.413717
FACE	2,1	1,0	2,0	63.668768	1.111230
FACE	2,1	3,1	2,0	58.717473	1.024813
DIHEDRAL	2,1	2,0		169.981901	2.966744
LENGTH	3,1	3,0		0.29453084	
AXIAL	0.0	3,0	3,1	81.531510	1.422993
FACE	3,1	2,0	3,0	57.534353	1.004164
FACE	3,1	4,1	3,0	59.920114	1.045803
DIHEDRAL	3,1	3,0		169.617161	2.960378
LENGTH	3,2	3,1		0.32491969	
AXIAL	0.0	3,1	3,2	80.650292	1.407613
FACE	3,2	2,1	3,1	59.999999	1.047198
FACE	3,2	4,2	3,1	62.565048	1.091966
DIHEDRAL	3,2	3,1		169.642082	2.960813
LENGTH	4,1	4,0		0.25318459	
AXIAL	0.0	4,0	4,1	82.727277	1.443863
FACE	4,1	3,0	4,0	54.334194	0.948311
DIHEDRAL	4,1	4,0		169.490046	2.958159
LENGTH	4,2	4,1		0.29858813	
AXIAL	0.0	4,1	4,2	81.413979	1.420942
FACE	4,2	3,1	4,1	58.796873	1.026199
DIHEDRAL	4,2	4,1		169.505737	2.958433

ONE FACE		COMPLETE STRUCTURE	
AREA	0.616453	AREA	12.329062
VOLUME	0.202350	VOLUME	4.047005
LENGTH	8.815519	LENGTH	143.204020

5-FREQUENCY ICOSAHEDRON, ALTERNATE

V(L) = 21 E(L) = 45 F(L) = 25

V(G) = 252 E(G) = 750 F(G) = 500

LENGTH	1,1	1,0		0.23179025	
AXIAL	0.0	1,0	1,1	83.344741	1.454640
FACE	1,1	0,0	1,0	71.590918	1.249497
FACE	1,1	2,1	1,0	61.797728	1.078574
DIHEDRAL	1,1	1,0		174.186995	3.040137
LENGTH	2,1	2,0		0.24724291	
AXIAL	0.0	2,0	2,1	82.898845	1.446858
FACE	2,1	1,0	2,0	65.444659	1.142225
FACE	2,1	3,1	2,0	59.197807	1.033197
DIHEDRAL	2,1	2,0		172.477804	3.010306
LENGTH	3,1	3,0		0.24508578	
AXIAL	0.0	3,0	3,1	82.961115	1.447945
FACE	3,1	2,0	3,0	59.964814	1.046583
FACE	3,1	4,1	3,0	58.369323	1.018737
DIHEDRAL	3,1	3,0		171.544544	2.994017
LENGTH	3,2	3,1		0.26159810	
AXIAL	0.0	3,1	3,2	82.484227	1.439621
FACE	3,2	2,1	3,1	61.674566	1.076424
FACE	3,2	4,2	3,1	59.999997	1.047198
DIHEDRAL	3,2	3,1		171.553503	2.994174
LENGTH	4,1	4,0		0.22568578	
AXIAL	0.0	4,0	4,1	83.520774	1.457713
FACE	4,1	3,0	4,0	56.125012	0.979566
FACE	4,1	5,1	4,0	59.101135	1.031509
DIHEDRAL	4,1	4,0		171.730190	2.997257
LENGTH	4,2	4,1		0.25516701	
AXIAL	0.0	4,1	4,2	82.670021	1.442864
FACE	4,2	3,1	4,1	59.162712	1.032584
FACE	4,2	5,2	4,1	62.432868	1.089659
DIHEDRAL	4,2	4,1		171.745039	2.997517
LENGTH	5,1	5,0		0.19814743	
AXIAL	0.0	5,0	5,1	84.314162	1.471560
FACE	5,1	4,0	5,0	54.204537	0.946048
DIHEDRAL	5,1	5,0		171.765753	2.997878
LENGTH	5,2	5,1		0.23159760	
AXIAL	0.0	5,1	5,2	83.350295	1.454737
FACE	5,2	4,1	5,1	58.430325	1.019802
DIHEDRAL	5,2	5,1		171.783924	2.998195
LENGTH	5,3	5,2		0.24534642	
AXIAL	0.0	5,2	5,3	82.953590	1.447813
FACE	5,3	4,2	5,2	60.070368	1.048426
DIHEDRAL	5,3	5,2		171.838518	2.999148

ONE FACE		COMPLETE STRUCTURE	
AREA	0.620672	AREA	12.413437
VOLUME	0.204862	VOLUME	4.097246
LENGTH	10.633763	LENGTH	179.530167

6-FREQUENCY ICOSAHEDRON, ALTERNATE

V(L) = 28 E(L) = 63 F(L) = 36

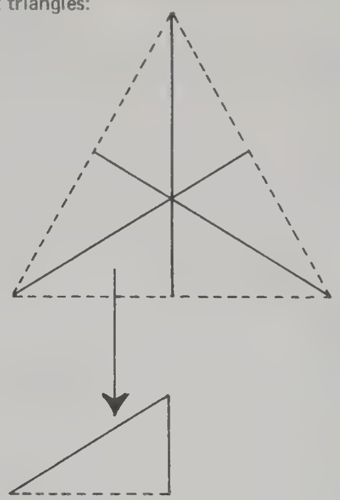
V(G) = 362 E(G) = 1080 F(G) = 720

LENGTH	1,1	1,0		0.19047686	
AXIAL	0.0	1,0	1,1	84.534954	1.475413
FACE	1,1	0,0	1,0	71.724745	1.251833
FACE	1,1	2,1	1,0	63.141629	1,102029
DIHEDRAL	1,1	1,0		175.412319	3.061523
LENGTH	2,1	2,0		0.20281969	
AXIAL	0.0	2,0	2,1	84.179635	1.469212
FACE	2,1	1,0	2,0	66.606874	1.162509
FACE	2,1	3,1	2,0	60.244049	1.051457
DIHEDRAL	2,1	2,0		174.131815	3.039174
LENGTH	3,1	3,0		0.20590774	
AXIAL	0.0	3,0	3,1	84.090703	1.467660
FACE	3,1	2,0	3,0	61.807500	1.078744
FACE	3,1	4,1	3,0	58.470501	1.020503
DIHEDRAL	3,1	3,0		173.178778	3.022540
LENGTH	3,2	3,1		0.21535373	
AXIAL	0.0	3,1	3,2	83.818582	1.462910
FACE	3,2	2,1	3,1	63.058991	1.100587
FACE	3,2	4,2	3,1	59.611143	1.040411
DIHEDRAL	3,2	3,1		173.202995	3.022963
LENGTH	4,1	4,0		0.19801258	
AXIAL	0.0	4,0	4,1	84.318046	1.471628
FACE	4,1	3,0	4,0	57.948445	1.011391
FACE	4,1	5,1	4,0	57.948447	1.011391
DIHEDRAL	4,1	4,0		172.856775	3.016920
LENGTH	4,2	4,1		0.21662821	
AXIAL	0.0	4,1	4,2	83.781857	1.462269
FACE	4,2	3,1	4,1	60.194424	1.050591
FACE	4,2	5,2	4,1	60.194427	1.050591
DIHEDRAL	4,2	4,1		172.843306	3.016685
LENGTH	5,1	5,0		0.18190825	
AXIAL	0.0	5,0	5,1	84.781497	1.479716
FACE	5,1	4,0	5,0	55.403753	0.966978
FACE	5,1	6,1	5,0	58.429183	1.019782
DIHEDRAL	5,1	5,0		173.170748	3.022400
LENGTH	5,2	5,1		0.20590773	
AXIAL	0.0	5,1	5,2	84.090701	1.467660
FACE	5,2	4,1	5,1	58.470502	1.020503
FACE	5,2	6,2	5,1	61.807496	1.078744
DIHEDRAL	5,2	5,1		173.178770	3.022540
LENGTH	5,3	5,2		0.21535373	
AXIAL	0.0	5,2	5,3	83.818583	1.462910
FACE	5,3	4,2	5,2	59.611144	1.040411
FACE	5,3	6,3	5,2	63.058989	1.100587
DIHEDRAL	5,3	5,2		173.202999	3.022963
LENGTH	6,1	6,0		0.16256722	
AXIAL	0.0	6,0	6,1	85.337645	1.489423
FACE	6,1	5,0	6,0	54.137622	0.944880
DIHEDRAL	6,1	6,0		173.240530	3.023618
LENGTH	6,2	6,1		0.18738340	
AXIAL	0.0	6,1	6,2	84.623971	1.476967
FACE	6,2	5,1	6,1	57.989368	1.012105
DIHEDRAL	6,2	6,1		173.254913	3.023869
LENGTH	6,3	6,2		0.20281970	
AXIAL	0.0	6,2	6,3	84.179636	1.469212
FACE	6,3	5,2	6,2	60.244049	1.051457
DIHEDRAL	6,3	6,2		173.318399	3.024977

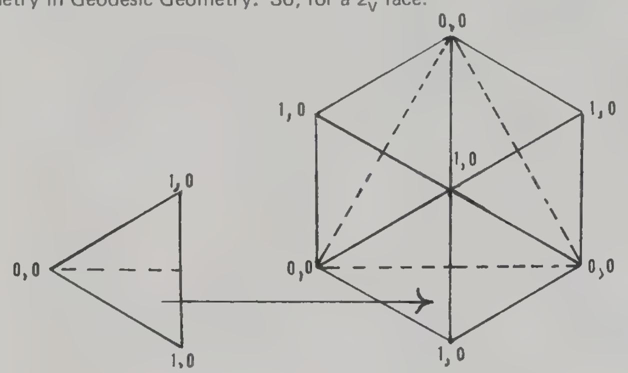
ONE FACE		COMPLETE STRUCTURE	
AREA	0.622988	AREA	12.459762
VOLUME	0.206246	VOLUME	4.124911
LENGTH	12.447279	LENGTH	215.779373

CHORD FACTORS AND ANGLES *continued*

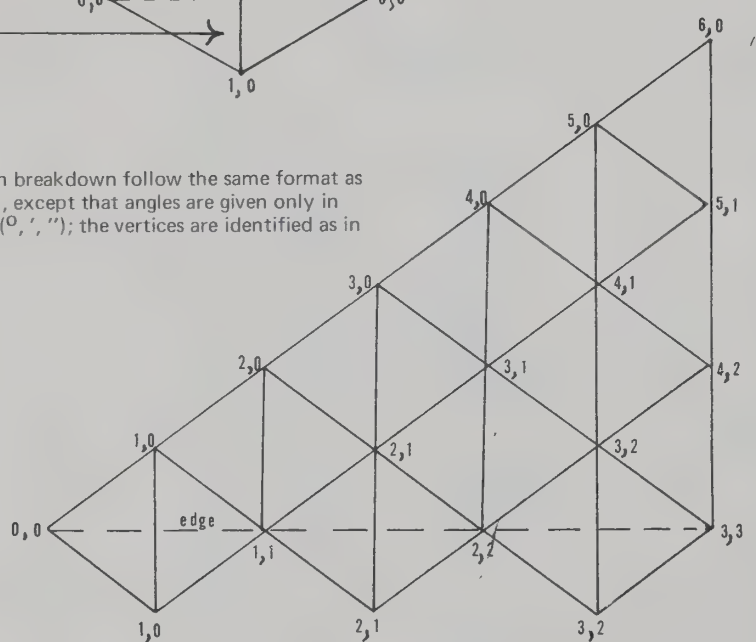
For triacon, to identify chords (struts) and angles you only have to use one of the six identical right triangles:



The coordinates given are identical for every right triangle. For a 2_V right triangle use up to line 1,0 - 1,0; for 4_V up to 2,0 - 1,1; for 6_V up to 3,0 - 2,1. See diagrams of symmetry in Geodesic Geometry. So, for a 2_V face:



The tables opposite for triacon breakdown follow the same format as those for alternate breakdown, except that angles are given only in degrees, minutes and seconds (°, ′, ″); the vertices are identified as in the diagram:



2-FREQUENCY ICOSAHEDRON, TRIACON

LENGTH	0,0	1,0		0.64085182
LENGTH	1,0	1,0		0.71364418
AXIAL	0.0	0,0	1,0	71° 18′ 41″
AXIAL	0.0	1,0	1,0	69° 5′ 42″
FACE	1,0	0,0	1,0	68°
FACE	0,0	1,0	1,0	56°

4-FREQUENCY ICOSAHEDRON, TRIACON

LENGTH	0,0	1,0		0.33607172
LENGTH	1,0	1,0		0.38941890
LENGTH	1,0	2,0		0.31338622
LENGTH	2,0	1,1		0.36284670
AXIAL	0.0	0,0	1,0	80° 19′ 35″
AXIAL	0.0	1,0	1,0	78° 46′ 21″
AXIAL	0.0	1,0	2,0	80° 59′ 6″
AXIAL	0.0	2,0	1,1	79° 32′ 51″
FACE	0,0	1,0	1,0	54° 35′ 23.1″
FACE	1,0	0,0	1,0	70° 49′ 13.7″
FACE	1,0	2,0	1,1	59° 53′ 56.4″
FACE	1,1	1,0	2,0	67° 49′ 32.0″
FACE	1,0	1,1	2,0	53° 6′ 31.5″

6-FREQUENCY ICOSAHEDRON, TRIACON

LENGTH	0,0	1,0		0.22425228
LENGTH	1,0	1,0		0.26427250
LENGTH	1,0	2,0		0.21877470
LENGTH	2,0	1,1		0.25561988
LENGTH	2,0	3,0		0.20603838
LENGTH	3,0	2,1		0.23181986
AXIAL	0.0	0,0	1,0	88° 30′ 16″
AXIAL	0.0	1,0	1,0	82° 24′ 25″
AXIAL	0.0	1,0	2,0	88° 43′ 12″
AXIAL	0.0	2,0	1,1	82° 39′ 25″
AXIAL	0.0	2,0	3,0	84° 5′ 13″
AXIAL	0.0	3,0	2,1	83° 0′ 39″
FACE	0,0	1,0	1,0	54° 16′ 8″
FACE	1,0	0,0	1,0	71° 27′ 58″
FACE	1,0	1,1	2,0	53° 34′ 53″
FACE	1,1	1,0	2,0	70° 05′ 25″
FACE	1,1	2,0	2,1	56° 19′ 42″
FACE	2,0	2,1	3,0	54° 27′ 30″
FACE	2,0	3,0	2,1	57° 16′ 29″
FACE	2,1	2,0	3,0	62° 4′ 56″

8-FREQUENCY ICOSAHEDRON, TRIACON

LENGTH	0,0	1,0		0.17026386
LENGTH	1,0	1,0		0.19937078
LENGTH	1,0	2,0		0.16701614
LENGTH	2,0	1,1		0.19563944
LENGTH	2,0	3,0		0.16103172
LENGTH	3,0	2,1		0.18493544
LENGTH	3,0	4,0		0.15533460
LENGTH	4,0	3,1		0.16871032
AXIAL	0.0	0,0	1,0	85° 7′ 0″
AXIAL	0.0	1,0	1,0	84° 16′ 44″
AXIAL	0.0	1,0	2,0	85° 12′ 36″
AXIAL	0.0	2,0	1,1	84° 23′ 11″
AXIAL	0.0	2,0	3,0	85° 22′ 58″
AXIAL	0.0	3,0	2,1	84° 41′ 40″
AXIAL	0.0	3,0	4,0	85° 36′ 11″
AXIAL	0.0	4,0	3,1	85° 9′ 41″

Face angles for 8-frequency not available.

useful math

Decimal Equivalents of Fractions

Use these to calculate fractions of an inch from the decimal obtained by multiplying radius times chord factors.

1/32	=	.03125
1/16	=	.06250
3/32	=	.09375
1/8	=	.12500
5/32	=	.15625
3/16	=	.18750
7/32	=	.21875
1/4	=	.25000
9/32	=	.28125
5/16	=	.31250
11/32	=	.34375
3/8	=	.37500
13/32	=	.40625
7/16	=	.43750
15/32	=	.46875
1/2	=	.50000
17/32	=	.53125
9/16	=	.56250
19/32	=	.59375
5/8	=	.62500
21/32	=	.65625
11/16	=	.68750
23/32	=	.71875
3/4	=	.75000
25/32	=	.78125
13/16	=	.81250
27/32	=	.84375
7/8	=	.87500
29/32	=	.90625
15/16	=	.93750
31/32	=	.96875
1	=	1.00000

$\pi = 3.14159265$

r = radius
b = base
h = altitude

Circumference of circle	$2\pi r$
Area of circle	πr^2
Area of sphere (skin)	$4\pi r^2$
Volume of sphere	$4/3\pi r^3$
Area of triangle	1/2 bh

Note: by doubling the diameter of a sphere, the surface area is increased by a factor of 4; the volume is increased by a factor of 8.

Conversion of feet to meters/meters to feet:

1 ft = 0.3048 meters
1 meter = 3.28084 ft

In any convex polyhedron, the number of faces (F), vertices (V) and edges (E) are related as follows:

$F + V = E - 2.$

This formula can be used in checking domes which are not complete spheres: consider the open bottom as a single face polygon; the number of sides equals the number of members along the perimeter of the dome's framework.

SEALANTS

Thiokol Joints Design Digest for Polysulfide Base Compounds

from Thiokol Chemical Corp.
Box 1296
Trenton, N. J. 08607

Technical data: Extrusion chart shows how much caulk is needed per lin ft of joint; coverage chart shows coverage per gallon for various film thicknesses.

from Harold A. Price Co., Inc.
P. O. Box 1389
Richmond, CA 94802

Hapco Products—caulks and Hypalon elastomeric sealant

from Price

Presstite Architectural sealants

from Presstite Division, Interchemical Corp.
39th & Chouteau
St. Louis, MO 63110

Brochure: "Seven Steps to Sure Sealing", on Dow Corning 780 Building Sealant

from Nearest Dow or Price

Sonneborn Sealants

from Sonneborn Building Products, Inc.
1700 South Mt. Prospect Road
Des Plaines, Illinois 60018

Sealant tapes (used in EXPO dome) PTI 606 architectural tape sealant

from Protective Treatments, Inc.
4401 West North Avenue
Chicago, Illinois 60639

Weatherban one-part sealant, Scotch Seal Metal Sealant, other information

from Adhesives, Coatings and Sealers Division
3M Company
2501 Hudson Road
St. Paul, Minnesota 55119

Vulkem one-part polyurethane sealants. Data from

Master Mechanics Co.
4475 East 175th Street
Cleveland, Ohio 44128

Backer Rod information

Foam Products Division
Haveg Industries Inc.
Middletown Industrial Park
Middletown, Delaware 19709

Uniroyal Rubber surfaces. Info from

Marine & Construction Products
312 North Hill Street
Mishawaka, Indiana

Gacoflex elastomeric waterproofing membrane and liquid roofing systems. Information from

Gaco Western, Inc.
P. O. Box 698
Tukwila Station
Seattle, Washington 98168

Stanlock structural neoprene gaskets. Catalog from

The Standard Products Company
Stanlock Department
Port Clinton, Ohio 43452

Catalog of pressure sensitive tapes. Vinyl, polyethylene, double faced tapes, electrical tape, etc.

from Arno Adhesive Tapes, Inc.
Michigan City, Indiana 46360

FOAM

Rigid fire retardant 2 pound polyurethane foam can be poured by mixing two liquids. Best source for low cost foam and good advice on proper technique:

Lloyd Fox
Douglas & Sturgess
730 Bryant Street
San Francisco, CA

Lots of current and very good information on foam: The John A. Hartsock Papers, and Olin bulletins GDI 005, 008, 009, 011, 012A, 013A and 015.

from Richard W. Gaetjen
Technical Sales Representative
Olin Plastics
Benicia Industrial Park
P. O. Box 847
Benicia, CA 94510

Specific Foam systems applications, formulations & techniques

William R. White
Flintkote Company
Sealzit Division
4075 Main Street
Riverside, CA

Free brochure: "The Use of Rigid Urethane Foam as a Structural Insulant"

from: Mobay Chemical Co.
Penn Lincoln Parkway West
Pittsburgh, PA 15205
Attn: Mr. Byron E. Beard

Also: Yellow pages for local foam applicators.

Foam guns:

Sealzit Division
The Flintkote Co.
P. O. Box 5347
Riverside, CA
Attn: W. R. White

Foam design

Deeds Design Associates
1706 West Arbor Drive
San Diego, CA 92103

FIBERGLASS

Ultra high-strength aerospace fiberglass, much stronger than conventional fiberglass. Technical Bulletin Ferro S-1014

from Ferro Fiberglass Corp.
Fiber Glass Road
Nashville, Tenn. 37211

Boat builders' fiberglass products—epoxy putty, glass tape, resin, etc.

from Glass Plastics Marine
200 Sayre Street
Rockford, Illinois 61101

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Fab-Dek: 35 mil Hypalon impregnated with neoprene. 3" wide roll, 11¢/lin ft. Adhesive $4.50/gallon. F.O.B. plant

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27279 Industrial Boulevard
Hayward, CA 94545
or
250 Pettit Avenue
Bellmore, L.I., N.Y. 11710

Fiberglass tape with isophthalic resin. Brochure from

TAP
1710 E. 12th Street
Oakland, CA 94606

Over 100 various pressure-sensitive tapes. Brochure: "Tapes for Industry" from

3M Company
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South San Francisco, CA

new materials

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Weather-proof Mylar, with ultraviolet resistants. Said to last two to five years outside exposure. About 19¢/sq. ft. from

Sears farm catalog

"Spooky Mylar"—aluminized on one surface. If used as a window you see your reflection and at the same time the trees outside. Not ultraviolet resistant.

from Transparent Products Corp.
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Los Angeles, CA 90015
Attn: A. Robert Suba

Clear Vinyl. About 6¢/sq. ft. from

Wards Farm Catalog

Brochure: "Dial-A-Spec Coated Fabrics" from

Flexifirm Products
2300 North Chico Avenue
El Monte, CA 91733

Coated fabrics (ripstop nylon, vinyl coated fiberglass, silicone rubber coated dacron, etc.) Brochure: "Coated Fabrics for Industry" from

3M Company
Film & Allied Products Division
1601 South Shamrock Avenue
Monrovia, CA 91016

Coated Nylon Fabrics. Brochures: "Protective Cover Fabrics" and "Engineered Fabrics for Industry" from

West Point Pepperell
Industrial Fabrics Division
111 West 40th Street
New York, N. Y. 10018

Parachutes: 24 ft. diameter canopies, white and in good condition. $22.50 plus postage and tax from

Security Parachute Co.
P. O. Box 3096
San Leandro, CA 94578

Plexiglas information. Beautiful color brochures, as well as data on Plexiglas sheet forming. Solar control series Plexiglas is produced in five densities. From

Rohm & Haas
Independence Mall West
Philadelphia, PA 19105

or

2150 Franklin Street
Oakland, CA 94612
Attn: Keith P. Mitchell

Korad acrylic film, can be used to surface metals, plywood, etc. Information from

Rohm & Haas (see above)

Acetate, Rayon, Nylon, Saran, Chromspun, etc. information. List of manufacturers and basic principles of manufacturing and use. Brochures, "Man-Made Fiber Fact Book" and "Guide to Man-Made Fibers" from

Man-Made Fiber Producers Association
350 5th Avenue
New York, N. Y. 10001

Rigid Vinyl. Fascinating brochure just arrived from Goodrich. "Designing with Rigid Vinyl." Comes in rods, extruded shapes, pipe, sheets and molded shapes. Sheets come in thicknesses from a few mils to several inches, many colors, and can be *heat-welded* with hot-air guns. You might be able to weld together a dome membrane at triangles' edges.

from B. F. Goodrich Chemical Co.
3135 Euclid Avenue
Cleveland, Ohio 44115

PLASTICS

Plastic sheets, thermopresses, rods, tubes for model making. Catalog from

Cope Plastics
1111 West Delmar Avenue
Godfrey, Illinois 62035

Glass reinforced thermoplastic sheets (Azdel) that can be formed on conventional metal stamping equipment. Fact sheet from

Gary Wagerson
G. R. T. L. Co.
No. 1 Gateway Center
Pittsburgh, PA 15222

Acrylic Plastic sheet, resistant to ultraviolet, can be adhered with heat and pressure alone. Technical data from

Rohm & Haas Co.
Independence Mall West
Philadelphia, PA 19015

Teflon, Plexiglas, fiberglass, Mylar, vinyl, foam guns, etc. A complete catalog of plastic materials and prices.

Plasticraft, Inc.
2800 North Speer
Denver, Colorado 80211

Factory seconds of clear acrylic; complete line of plastics. Abe makes deals.

Abe Schuster Fiberglass
6211 Telegraph Avenue
Oakland, CA 94609

Tedlar-coated Fiberglass Panels

Ornyte Fiberglass Panels
711 Olympic Boulevard
Santa Monica, CA

MISCELLANEOUS

Skylights: clear or opaque, these acrylic skylights are reasonably priced if you buy just the plastic part without the frame. A 30" circular bubble is about $20. Brochure: "Wasco Skydomes"

from Western MacArthur Co.
460 Park Avenue
San Jose, CA 95110

Best plywood for domes: Duraply flat panel siding is exterior Douglas Fir plywood with phenolic resin-fiber surface, designed for severe weather exposure. Guaranteed against delamination for life of building. Brochure from

U. S. Plywood Corp.
777 Third Avenue
New York, N. Y. 10017

Energy absorbing material: polymeric rubber foam for damping sound and vibes. Brochure from

Norton Research Corp.
70 Memorial Drive
Cambridge, Mass. 02142

"Living hinge": tough polypropylene hinge, has been flexed 1,000,000 times without breaking. You can use it for vents, doors and it should make waterproofing the hinged edge simple. About 30¢/ft, comes in rolls.

Stokes Molded Products
75 Taylor Street
Trenton, N. J. 08604

Lock and Key Extrusion. A simple way to install glass or plastic windows in wood or metal panels. Information from

Alasco Rubber & Plastics Corp.
839 Malcolm Road
Burlingame, CA

Laminite Cardboard, unbelievably tough, fire-retardant, and light. Samples from

Laminite Division
Tri-Wall Containers, Inc.
One Dupont Street
Plainview, N. Y. 11803

Strap and strapping tools

A. J. Gerrard & Co.
400 East Touhy Avenue
Des Plaines, Illinois

Check yellow pages (*strapping*) for closest location, or other companies.

Rust-proof MONEL staples, staple guns:

Duo Fast California
1465 Third Street
San Francisco, CA

Nails. If you are using nails in domes, always get *hot dip* galvanized nails. Electro-galvanized nails rust very quickly. Also, the hot dip have much greater holding power. There are two types of super strong nails—annular grooved and threaded nails that have much greater holding power than ordinary nails.

Foam Panels:

Dyna Domes
22226 North 23rd Avenue
Phoenix Arizona 85027

Aluminum Co. of America
1501 Alcoa Building
Pittsburgh, Pa.

Apache Foam Products
1005 North McKinley Road
Belvedere, Illinois 61008

General Plastics Co.
3481 South 35th Street
Tacoma, Washington 98409

others: write

Mobay Chemical Co.
Penn Lincoln Parkway West
Pittsburgh, PA 15205

Extrusions: rubber and synthetic, about 40¢–$1/ft, making the mold is surprisingly cheap, as low as $40. This means you can design an extrusion tailored to your needs. From

Wefco Rubber Manufacturing
1655 Euclid Avenue
Santa Monica, CA 90404

Air building of vinyl by Ant Farm—see p. 55.

BIBLIOGRAPHY

We've found these publications to be especially good for dome design and building. The books marked with an * are available from the Whole Earth Catalog, 558 Santa Cruz Avenue, Menlo Park, CA 94025.

*Baer, S. *The Dome Cookbook,* Corrales, N. M.: The Lama Foundation, 1968.

Beard, Col. R. S., *Patterns in Space,* 1965. $7.50 from Fibonacci Quarterly, St. Mary's College, CA 94575.

*Borrego, J. *Space Grid Structures,* Cambridge, Mass: MIT Press, 1968

Clinton, J.D. *Structural Design Concepts for Future Space Missions,* Progress Report—NASA Contract 606—607 (November 1965)

*Cundy, H.M. and Rollett, A.P. *Mathematical Models,* London: Oxford University Press, 1961

*Fuller, R. B. *World Design Science Decade Documents 1965-1975,* Carbondale, Illinois: World Resources Inventory Office, 1965. Volume II has section by Fuller—"World Design Initiative"—with photos and explanations of domes and tensegrity structures not available elsewhere. Vol. III contains *Omnidirectional Halo.*

Fuller, R. B. Geodesic Patents (see p. 44)

Ghyka, M. *The Geometry of Art and Life,* New York: Sheed and Ward, 1946

Kern, K. *The Owner-Built Home,* Oakhurst, CA: Ken Kern Drafting, 1961

*Marks, R. W. *The Dymaxion World of R. Buckminster Fuller,* Carbondale, Illinois: Southern Illinois University Press, 1960

*Marks, R. W. *The New Mathematics Dictionary and Handbook,* New York: Bantam Books, Inc., 1964. Simple and concise. Good if you know nothing about math.

Nervi, P. L. *Structures,* N. Y.: McGraw-Hill, 1956.

*Otto, F. *Tensile Structures, Vols. I and II,* Cambridge, Mass: MIT Press, 1967; 1969

*Popko, E. *Geodesics,* Detroit, Michigan: University of Detroit Press, 1968

*Skeist, I. *Plastics in Building.* New York: Van Nostrand-Reinhold, 1966

*Steinhaus, H. *Mathematical Snapshots,* New York: Oxford University Press, 1960

Stuart, D. "On the Orderly Subdivision of Spheres," Student Publication of the School of Design, North Carolina State University (At Raleigh), 1955

Stuart, D. "Polyhedral and Mosaic Transformations," Student Publication of the School of Design, North Carolina State University (At Raleigh), 1963

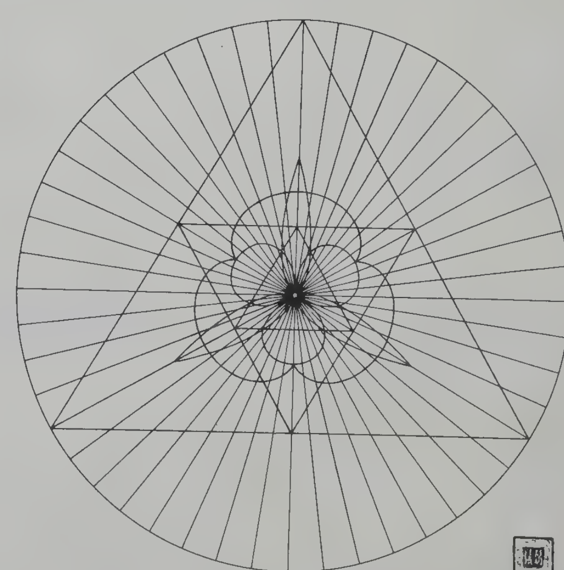
*Thompson, D. W. *On Growth and Form,* New Rochelle, N. Y.: Cambridge University Press, 1917; 1952; 1961

Warring, R. and Lewis, G. *Glass Fibre for Amateurs,* Hemel Hempstead, Herts, England: Model & Allied Publications.

*White, L. L. *Aspects of Form,* Bloomington, Indiana: Indiana University Press, 1951

Williams, R. E. *Handbook of Structure. Part I: Polyhedra & Spheres,* 1968. Available from Douglas Aircraft Co., Advanced Research Laboratories, 5251 Bolsa Avenue, Huntington Beach, CA 92647. This has been the clearest and most useful publication I've seen on polyhedra and spheres. You can learn a great deal from this book alone.

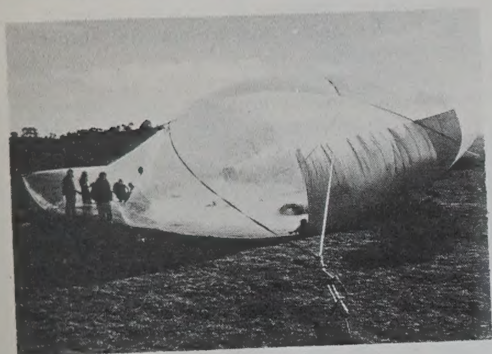
Conchoidal Transformation of Triangles. When all points in sides of the three triangles move in at the same rate on their lines through center, they will form the floral pattern when midpoints of outer sides meet at the center.



From *Patterns in Space*

unclassifieds

Builders and designers working with new concepts; let us know if you wish to be added; no charge.



Air buildings, nomadic visions.

ANT FARM
247 Gate Five Road
Sausalito, CA 94965

Dome design, construction, traveling workshops, classes.

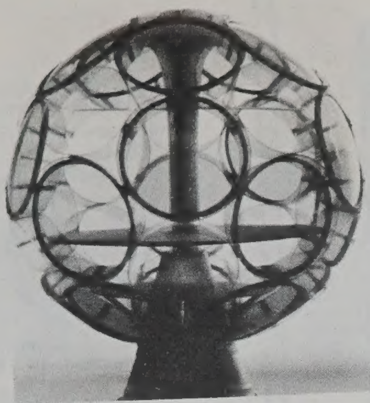
Pacific Domes
Box 1692
Los Gatos, CA 95030

Prefab kits and construction. Hubs for wood strut domes, foam and fiberglass research and design.

Dyna Domes
22226 North 23rd Avenue
Phoenix, Arizona 85027

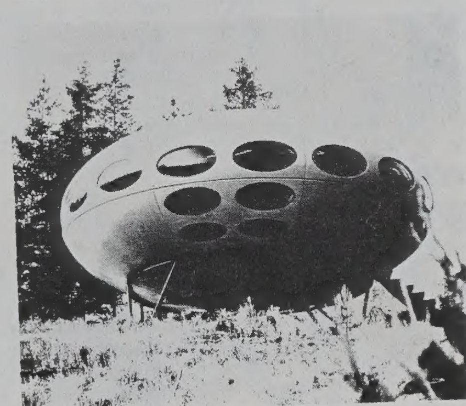
Designer of domes and experimental structures.

Robt. Easton
Domebuilders Co.
975 Mariposa Lane
Santa Barbara, CA 93103



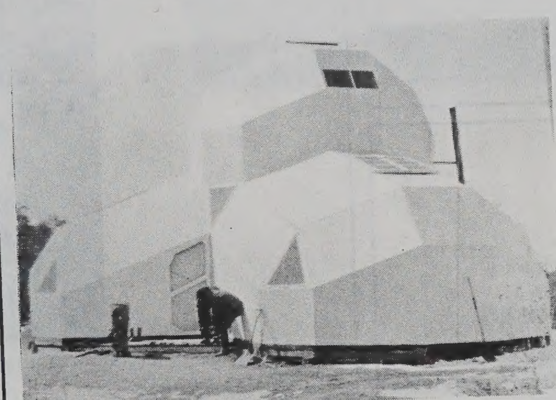
Spherical design; 30' spherical home on pedastal; circular inflated mylar windows; in model stage.

Philo Farnsworth
Box 152
Bolinas, CA 94924



Foam-fiberglass pods, designed in Finland.

Futuro Corp.
1900 Rittenhouse Square
Philadelphia, PA 19103

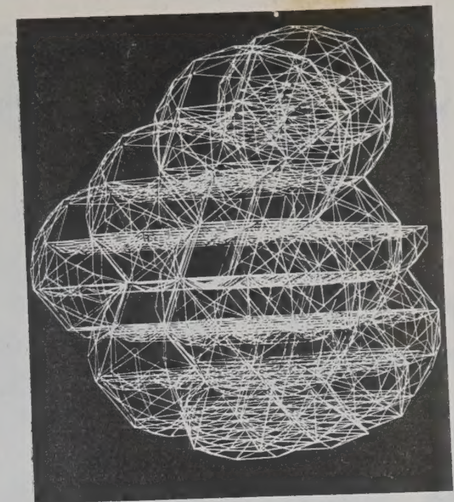


Environmental designers, artists, lecturers, community planners.

Libre
Box 98
Gardiner, Colorado 81040

Pod that can be erected in three hours.

O'Dome
Tension Structures, Inc.
663 Fifth Avenue
New York, N. Y. 10022

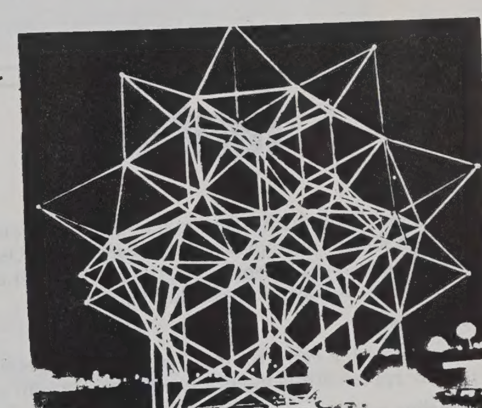


Currently preparing book on modular architecture based on design principles in nature.

Peter Pearce
SYNESTRUCTICS, Inc.
7527 Coldwater Canyon Avenue
North Hollywood, CA 91605

Large scale aluminum geodesic domes.

Temcor
2825 Toledo Street
Torrance, CA 90503



Zomes, solar heating, lectures, design.

ZOMEWORKS
P. O. Box 712
Albuquerque, NM 87103

But there is hope in sight. The very young! The university students are intuitively skeptical of the validity of any and all evolution-blocking establishment; they are therefore negatively preoccupied. However, high school youth think spontaneously and positively in astro- and electromagnetic technology and their realistic uses. The young of all ages abhor hypocrisy. They are bored with obsolete up and down dancing, with bureaucratic inertia, and with any kind of fear-built gauges. They are bored with the immobilization of resources known as security. They disdain white, gray, black and blue lies. The students and school children around the world have idealistic compassion for all humanity. There is a good possibility that they may take over and successfully operate spaceship Earth.

R. Buckminster Fuller

fantasies

Dome Farm

Find a farm, with barn. Testing site for new structures. Tie it into our high school, so students can help and learn. Use the site as a research and development center for development of low cost/lightweight/easy to assemble/beautiful shelters.

Rock Dome

A large portable dome for rock festivals/with specially designed speaker system/White interior for 360 degree light projection.

Traveling workshop

We've prepared a traveling workshop: slide show, movie of dome building, models, structural skeleton, classes.

Build your own school

Get some land in the country. Get water, power, then build a large dome as a meeting place/auditorium/shop/living quarters/combination of these. This will give you a base of operations from which to build the rest of the school.

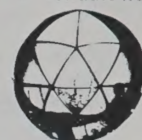
Among the Pawnees of northern Kansas and Southern Nebraska, the priest, during the ceremonial of the Hako, draws a circle with his toe. "The circle represents a nest," such a priest is reported to have said, "and it is drawn by the toe because the eagle builds its nest with its claws. Although we are imitating the bird making its nest, there is another meaning to the action; we are thinking of Tirawa making the world for the people to live in. If you go on a high hill and look around, you will see the sky touching the earth on every side, and within this circular enclosure the people live. So the circles we have made are not only nests, but they also represent the circle Tirawa-atius has made for the dwelling place of all the people. The circles also stand for the kinship group, the clan, and the tribe."

Alice C. Fletcher,
The Hako: A Pawnee Ceremony

last minute

Sphere on a pedestal, either hung from cables from five telephone poles or on a stem like a flower. Different level lofts made by octet trusses. Don't close off any part of the sphere by putting a floor all the way across.

A conduit frame, burlap or chicken wire stretched over, sprayed with 2" foam.



Alan Schmidt is building a dome for Kriyananda: wood struts, fiberglass put on with aluminum nails with neoprene washers, pop-in styrofoam insulating panels.

Completely transparent dome with pop-in insulating panels. Adjust dome to the season, change light patterns to block or admit sunlight, view different parts of landscape.

Hang a swing in your dome for quick passage from one side to another.

Aluminum and galvanized steel can be used as skins for domes. Aluminum doesn't have to be painted, will last about 25 years (near the ocean it should be anodized), and is soft. Galvanized steel has to be painted and is stiff.

You can use thin metal if you spray the inside of the dome with foam. The panels should be sprayed from the inside with automobile undercoating or something like it to keep the dome from booming.

With a metal skin and a wood frame the panels can be shingled. Cut the panels an inch or two larger than the actual size of the triangles (Then when the panels are attached to the frame they overlap. See metal tube domes). For sealing you put a strip of vinyl foam or tape caulk over the struts before attaching the panels. The panels can be stapled to the frame. You should use a staple gun that makes the staples curve outward. For thick metal you can rent an air stapler.

I remember seeing an old movie of the first helicopters—they were of every conceivable design. One had a giant parasol type thing that telescoped, causing the copter to hop up and down. Each one looked entirely different. If we get 500 people building domes, we'll have a marvelous array of prototypes.

Historically people who have had control of special areas have huddled in groups, invented complex—sometimes mystical—mazes for the uninitiated to struggle through. Like the carpenters' union. You have to strip concrete forms for 6 months before they let you learn how to frame. The old guys don't want the young ones to come along too fast. If you give kids access—don't weight them down with traditional static step-by-step rituals—they'll amaze you by their speed. Perhaps it has something to do with their familiarity and ease with communications—TV, etc. Look what happened when kids got ahold of guitars.

Last resort for leaking plywood domes: composition shingles.

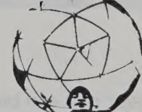
As man begins exploring space,
domes appear on earth.

Pour triangles of foam, put up a framework, lay triangles on it, foam the seams, fiberglass exterior into a monolithic membrane, remove the framework. Foam in windows and vents. Use some old salvaged wood to frame door and windows. Use other small pieces of wirebrushed wood for a mantle or altar.

There are a number of mathematicians and designers currently working on domes. Many of them have evolved sophisticated designs for domical structures—they all acknowledge that implementation of their ideas will take the best technology, and large amounts of money. As an individual, unfettered by thinking about big finance, or grants, you have a great degree of freedom in dome design. You can try out your idea. Design, then try to *build* your design, and then by all means *live* in it. How else can you know if it works?

I once stood in the rain by a puddle watching the rain drops hit and glimmering transparent half-bubbles float on the water.

A dome of diamonds folded inwardly along the vertical axis. See laminar patent, p. 44. Make the diamonds of cardboard, spray exterior with resin, erect dome, spray inside with foam.



Clear dome with sun screen on a track that runs around the perimeter, adjusting it to block the sun and create privacy.

With the dome around me, I feel like the pit inside an apricot, butterfly inside cocoon....

Spray-up fiberglass panels with bolt-together edges, neoprene washer in between.

. . . ALL PARTS WERE COLOR CODED SO THAT THE AFGHAN PEOPLE WOULD BE ABLE TO ERECT IT BY PUTTING THE RED END TO THE RED HOLE ON THE HUB AND THE BLUE TO BLUE ETC. THEY DIDN'T KNOW WHAT THEY WERE BUILDING AT ALL. THEY THOUGHT IT WOULD BE A CONVENTIONAL RECTILINEAR STRUCTURE, BUT SUDDENLY FOUND THEY HAD PRODUCED A HEMISPHERICAL STRUCTURE. THEY WERE BOGGLE EYED AND EXCITED. THE WORKERS BEGAN TO SHOOT THE SHOOTS DOWN THE TAUT NYLON-GEON-SKIN OF THE DOME. . . . WHEN THE AFGHAN PEOPLE SAW THAT THE AFGHAN WORKMEN HAD PUT UP A NEW DOME STRUCTURE THEY ATTRIBUTED ITS SPHERICAL SUCCESS TO THE AFGHANS' CRAFT SKILL. THEY SAID TO THE AFGHAN WORKMEN—SHOOTING THE SHOOTS DOWN THE DOME—"YOU ARE GOOD DOME BUILDERS." THE WORKMEN REPLIED: "YES WE ARE."

From *World Design Science Decade, Vol. II* (See p. 54)

Pacific Domes
Box 1692
Los Gatos, CA 95030